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(54) Title: IMPROVED CATALYST SYSTEM

(57) Abstract: A continuous carbonylation process for high turnover carbonylation, and a carbonylation reaction medium and product stream thereof. The process comprises carbonylating an ethylenically unsaturated compound with carbon monoxide in the presence of a source of hydroxyl groups and a catalyst system. The catalyst system comprising: (a) a bidentate phosphine, arsine or stibine ligand; and (b) a catalytic metal selected from a group VIB or group VIIIB metal or a compound thereof. The catalytically active concentration of said catalytic metal, measured as the ACCF (product Kg . hr^{-1} . Dm^{-3}), is maintained at less than 0.5.

IMPROVED CATALYST SYSTEM

The present invention relates to a process for the carbonylation of ethylenically unsaturated compounds, a novel carbonylation reaction medium and a process for the carbonylation of ethylenically unsaturated compounds using a novel carbonylation reaction medium.

The carbonylation of ethylenically unsaturated compounds using carbon monoxide in the presence of an alcohol or water and a catalyst system comprising a Group VIII metal, eg. palladium, and a phosphine ligand eg. an alkyl phosphine cycloalkyl phosphine, aryl phosphine, pyridyl phosphine or bidentate phosphine, has been described in numerous European patents and patent applications, eg. EP-A-0055875, EP-A-04489472, EP-A-0106379, EP-A-0235864, EP-A-0274795, EP-A-0499329, EP-A-0386833, EP-A-0441447, EP-A-0489472, EP-A-0282142, EP-A-0227160, EP-A-0495547 and EP-A-0495548. In particular, EP-A-0227160, EP-A-0495547 and EP-A-0495548 disclose that bidentate phosphine ligands provide catalyst systems which enable higher reaction rates to be achieved.

A greater improvement to such bidentate phosphine ligands is provided in WO 96/19434 which discloses a bridging group in the form of an optionally substituted aryl moiety, linked to the said phosphorous atoms via available adjacent carbon atoms on the said aryl moiety. Such a ligand is more stable and leads to reaction rates which are significantly higher than those previously disclosed and produces little or no impurities for the carbonylation of ethylene. Each phosphorous atom in the said ligand is also linked to two tertiary carbon atoms.

However, conventional metal-catalysed reactions, such as those described in WO 96/19434 tend to suffer from the drawback that the catalyst tends to de-activate over the course of a period of continuous operation as the palladium compound is reduced to palladium metal, thus contributing an important factor in the economic viability of the process. WO 01/10551 addressed this problem via the use of stabilising compounds such as polymeric dispersants in the reaction medium, thus improving the recovery of metal which has been lost from the catalyst system. Interestingly, however, none of the examples actually relate to a continuous process and, therefore, little knowledge of the effect on recovery of metal or other factors can be obtained from the disclosure.

Although catalyst systems have been developed which exhibit reasonable stability during the carbonylation process and permit relatively high reaction rates to be achieved, there still exists a need for improved catalyst activity. Suitably, the present invention aims to provide, inter alia, an improved continuous process for carbonylation of ethylenically unsaturated compounds and a carbonylation reaction medium for such continuous processes for carbonylating ethylenically unsaturated compounds. In particular, improvements to bidentate phosphine ligand containing catalyst systems are sought.

Palladium and other precious metals in Group VIB or Group VIIIB are expensive commodities and as mentioned above the rate of use of this commodity contributes to the economic viability of carbonylation processes using such metals. One expression of the efficiency of the use of the

catalytic metal is turnover number (TON) which is defined as Moles of Carbonylation Product/Moles of Catalytic Metal. A high TON number indicates a more efficient and cost effective process. In the past efforts have concentrated on high rates of production of carbonylation product to maximise yield in this respect.

Catalyst activity per unit volume of reaction medium can be expressed in terms of the production of carbonylation product per unit time from a unit volume of reaction medium, and is measured in units of product $kg.hr^{-1}.dm^{-3}$. This measure is known as the active catalyst concentration factor (ACCF).

According to a first aspect of the present invention there is provided a continuous carbonylation process for high turnover carbonylation comprising carbonylating an ethylenically unsaturated compound with carbon monoxide in the presence of a source of hydroxyl groups and a catalyst system comprising (a) a bidentate phosphine, arsine or stibine ligand, and (b) a catalytic metal selected from a group VIB or group VIIIB metal or a compound thereof wherein the catalytically active concentration of said catalytic metal, measured as the ACCF (product $Kg.hr^{-1}.dm^{-3}$) is held at less than 0.5.

By continuous herein is meant that the respective concentrations of ethylenically unsaturated compound, carbon monoxide, the source of hydroxyl groups and, preferably, the catalyst system are held substantially constant during the process.

According to a second aspect of the present invention there is provided a carbonylation reaction medium and product stream thereof for a continuous carbonylation process comprising in the reaction medium an ethylenically unsaturated compound, carbon monoxide, a source of hydroxyl groups and a catalyst system comprising:-

(a) a bidentate phosphine, arsine or stibene ligand, and

(b) a catalytic metal selected from a group VIB or group VIIIB metal or a compound thereof wherein the catalytically active concentration of said catalytic metal in said medium, measured as the ACCF (product $kg.hr^{-1}.dm^{-3}$), is maintained at less than 0.5.

For the avoidance of doubt, the ACCF of the carbonylation reaction medium for a continuous process is generally measured in the product stream.

Preferred features of the invention will be apparent from the dependent claims, and the description which follows.

Preferably, the ACCF is less than 0.4, more preferably, less than 0.35, most preferably, less than 0.30.

Typically, the ACCF range is 0.005 to 0.49, more typically 0.01 to 0.39, most typically, 0.05 to 0.34. Especially preferred is an ACCF of 0.1 to 0.29 $kg.dm^{-3}.hr^{-1}$.

Typically, the low ACCF of the present invention is held or maintained by suitable dilution of the carbonylation reaction medium. Preferably, dilution is effected with one of the components of the reaction medium other than

the catalyst metal, more preferably, by means of an additional solvent, carbonylation product or hydroxyl group containing compound. The carbonylation product, when capable of acting as a solvent is particularly preferred.

Preferably, the catalyst system also includes as a further component (c) an acid.

By "acid", we mean an acid or salt thereof, and references to acid should be construed accordingly.

Suitably, all of components a), b) and c) (when present) of the catalyst system can be added in situ to the reaction vessel wherein the carbonylation is to take place. Alternatively, the components a), b) and c) (when present) can be added sequentially in any order to form the catalyst system, or in some specified order, either directly into the vessel or outside the vessel and then added to the vessel. For instance, the acid component c) (when present) may first be added to the bidentate ligand component a), to form a protonated ligand, and then the protonated ligand can be added to the metal or compound thereof (component b)) to form the catalyst system. Alternatively, the ligand component a) and metal or compound thereof (component b)) can be mixed to form a chelated metal compound, and the acid (component c)) is then optionally added. Alternatively, when the acid component c) is to be used, any two components can be reacted together to form an intermediate moiety which is then either added to the reaction vessel and the third component added, or is first reacted with the third component and then added to the reaction vessel. However, in the continuous process it is preferred that the

components a), b) and c) are all added independently of each other at a continuous rate.

The present invention is also directed to a catalyst system as defined above wherein the relative molar concentrations of both the bidentate ligand and the acid are at levels in excess of those previously envisaged, leading to surprising and unexpected advantages when using the catalyst system in the carbonylation of ethylenically unsaturated compounds, and the alleviation or at least reduction of at least some of the disadvantages of the prior art systems. In any case, the use of a catalyst system of the present invention leads at least to a more stable system, with improved turnover numbers in carbonylation reactions of ethylenically unsaturated compounds.

The amount of bidentate ligand used can vary within wide limits. Preferably, the bidentate ligand is present in an amount such that the ratio of the number of moles of the bidentate ligand present to the number of moles of the Group VIB or VIIIB metal present is from 1 to 50 eg. 1 to 10 and particularly from 1 to 5 mol per mol of metal. More preferably, the mol:mol range of compounds of formula I to Group VIIIB metal is in the range of 1:1 to 3:1, most preferably in the range of 1:1 to 1.25:1. Conveniently, the possibility of applying these low molar ratios is advantageous, as it avoids the use of an excess of the compound of formula I and hence minimises the consumption of these usually expensive compounds. Suitably, the catalysts of the invention are prepared in a separate step preceding their use in-situ in the carbonylation reaction of an ethlenically unsaturated compound.

However, in an excess acid system the ligand may be present in the catalyst system, or precursor thereto, in excess so that the ratio of said ligand to the said metal (i.e. component a) to component b)) is at least a 2:1 molar ratio. Preferably, the ratio of said ligand to the said metal in such systems is greater than a 2:1 molar ratio, more preferably in the range 2:1 to 1000:1, even more preferably in the range 2.5:1 to 1000:1, yet more preferably in the range 3:1 to 1000:1, even more preferably in the range 5:1 to 750:1, more preferably in the range 7:1 to 1000:1, especially in the range 8:1 to 900:1, still more preferably in the range 10:1 to 500:1, yet still more preferably in the range 20:1 to 400:1, even more preferably in the range 50:1 to 250:1, most preferably in the range in excess of 50:1, for example 51:1 and upwards, more specifically 51:1 to 250:1 or even to 1000:1. Alternatively, the said ratio can be in the range 15:1 to 45:1, preferably 20:1 to 40:1, more preferably 25:1 to 35:1.

As stated above, acid may be present and this may be in excess in the catalyst system, or precursor thereto, preferably, in such quantity that the ratio of said acid to the said ligand (i.e. component c) to component a)) is at least a 2:1 molar ratio. Preferably, the ratio of said acid to the said ligand in such excess acid systems is greater than a 2:1 molar ratio, more preferably in the range 2:1 to 100:1, even more preferably in the range 4:1 to 100:1, yet more preferably in the range 5:1 to 95:1, still more preferably in the range greater than 5:1 to 95:1, yet more preferably in the range greater than 5:1 to 75:1, more preferably in the range 10:1 to 50:1, even more

preferably in the range 20:1 to 40:1, still more preferably in the range greater than 20:1 to 40:1 (e.g. 25:1 to 40:1, or 25:1 to less than 30:1), more preferably in excess of 30:1, suitably with any of the upper limits provided hereinbefore (e.g. 30:1 to 40:1) , or 50:1, etc.), or more preferably in excess of 35:1, yet more preferably in excess of 37:1, suitably either with any of the upper limits provided hereinbefore. Each of the ranges in this paragraph can be used in conjunction with each of the ligand to metal ratio ranges disclosed hereinabove, i.e. ratios of component a) to component b).

The advantages in working within the ligand to metal, and acid to ligand ratios, set out above in an excess acid system are manifest in that the stability of the catalyst system is further improved over that surprisingly provided by the low ACCF, as evidenced by further increases in the turnover number (TON) of the metal. By improving the stability of the catalyst system, the usage of metal in the carbonylation reaction scheme is kept to a minimum.

In effect, the level of acid should be such that for the particular bidentate ligand employed, the level of acid should be such that phosphine, arsine or stibine is fully protonated. Hence, to show the improved effects, the level of ligand should be above some minimum level, as given by the ligand:metal molar ratio, and the level of acid should be above some minimum level with respect to the level of ligand present to encourage protonation, as given by the acid:ligand molar ratio.

Preferably, the acid is present in the catalyst system, or precursor thereto, in such quantity that the molar ratio

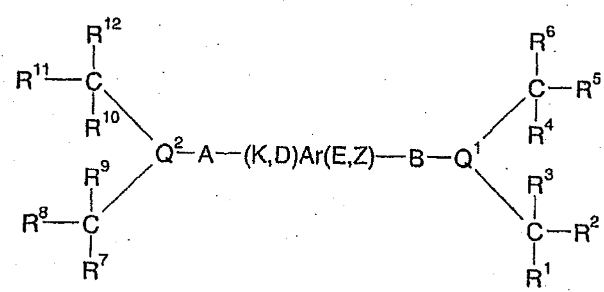
of said acid to said metal (i.e. component c) to component b)) in the excess acid system is at least 4:1, more preferably from 4:1 to 100000:1, even more preferably 10:1 to 75000:1, yet more preferably 20:1 to 50000:1, yet still more preferably 25:1 to 50000:1, yet still more preferably 30:1 to 50000:1, yet even more preferably 40:1 to 40000:1, still more preferably 100:1 to 25000:1, more preferably 120:1 to 25000:1, more preferably 140:1 to 25000:1, yet still more preferably 200:1 to 25000:1, most preferably 550:1 to 20000:1, or greater than 2000:1 to 20000:1. Alternatively, the said ratio can be in the range 125:1 to 485:1, more preferably 150:1 to 450:1, even more preferably 175:1 to 425:1, yet even more preferably 200:1 to 400:1, most preferably 225:1 to 375:1. Each of these ranges in this paragraph can be used in conjunction with each of the ligand to metal ratio ranges disclosed hereinabove, i.e. ratios of component a) to component b), and/or each of the acid to ligand ratio ranges disclosed hereinabove, i.e. ratios of component c) to component a).

For the avoidance of any doubt, all of the aforementioned ratios and ratio ranges apply to all of the ligand embodiments set out in more detail hereinafter. However, it should also be borne in mind that the presence of acid is optional and not essential to the present invention. Accordingly, the possibility of excess acid in the system is also optional and not essential to the present invention.

The advantages of the ACCF aspects of the invention, set out above are manifest in that the stability of the catalyst system is improved, as evidenced by increases in the turnover number (TON) of the metal. By improving the

stability of the catalyst system, the usage of metal in the carbonylation reaction scheme is kept to a minimum.

In one embodiment of the present invention, the bidentate phosphine ligand is of general formula (I)



(I)

wherein:

Ar is a bridging group comprising an optionally substituted aryl moiety to which the phosphorus atoms are linked on available adjacent carbon atoms;

A and B each independently represent lower alkylene;

K, D, E and Z are substituents of the aryl moiety (Ar) and each independently represent hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, $C(S)R^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$, or $-J-Q^3(CR^{13}(R^{14})(R^{15})CR^{16}(R^{17})(R^{18})$ where J represents lower alkylene; or two adjacent groups selected from K, Z, D and E together with the carbon atoms of the aryl ring to which they are attached form a further phenyl ring, which is optionally substituted by one or more substituents selected from hydrogen, lower alkyl, halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, $C(S)R^{25}R^{26}$, SR^{27} or $C(O)SR^{27}$;

R^{13} to R^{18} each independently represent hydrogen, lower alkyl, aryl, or Het, preferably each independently represent lower alkyl, aryl, or Het;
R^{19} to R^{27} each independently represent hydrogen, lower alkyl, aryl or Het;

R^1 to R^{12} each independently represent hydrogen, lower alkyl, aryl, or Het, preferably each independently represent lower alkyl, aryl, or Het;

Q^1, Q^2 and Q^3 (when present) each independently represent phosphorous, arsenic or antimony and in the latter two cases references to phosphine or phosphorous above are amended accordingly, with preferably both Q^1 and Q^2 representing phosphorus, more preferably all of Q^1, Q^2 and Q^3 (when present) representing phosphorus.

Suitably, the bidentate phosphines of the invention should preferably be capable of bidentate coordination to the Group VIB or Group VIIIB metal or compound thereof, more preferably to the preferred palladium.

Preferably, when K, D, E or Z represent $-J-Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$, the respective K, D, E or Z is on the aryl carbon adjacent the aryl carbon to which A or B is connected or, if not so adjacent, is adjacent a remaining K, D, E or Z group which itself represents $-J-Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$.

Specific but non-limiting examples of bidentate ligands within this embodiment include the following: 1,2-bis-(di-tert-butylphosphinomethyl)benzene, 1,2-bis-(di-tert-pentylphosphinomethyl)benzene, 1,2-bis-(di-tert-

butylphosphinomethyl)naphthalene. Nevertheless, the skilled person in the art would appreciate that other bidentate ligands can be envisaged without departing from the scope of the invention.

The term "Ar" or "aryl" when used herein, includes five-to-ten-membered, preferably, six-to-ten membered carbocyclic aromatic groups, such as phenyl and naphthyl, which groups are optionally substituted with, in addition to K, D, E or Z, one or more substituents selected from aryl, lower alkyl (which alkyl group may itself be optionally substituted or terminated as defined below), Het, halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$ or $C(S)NR^{25}R^{26}$ wherein R^{19} to R^{27} each independently represent hydrogen, aryl or lower alkyl (which alkyl group may itself be optionally substituted or terminated as defined below). Furthermore, the aryl moiety may be a fused polycyclic group, e.g. naphthalene, biphenylene or indene.

By the term "a metal of Group VIB or Group VIIIB" in a compound of formula I we include metals such as Cr, Mo, W, Fe, Co, Ni, Ru, Rh, Os, Ir, Pt and Pd. Preferably, the metals are selected from Ni, Pt and Pd. More preferably, the metal is Pd. For the avoidance of doubt, references to Group VIB or VIIIB metals herein should be taken to include Groups 6, 8, 9 and 10 in the modern periodic table nomenclature.

The term "Het", when used herein, includes four-to-twelve-membered, preferably four-to-ten-membered ring systems, which rings contain one or more heteroatoms selected from nitrogen, oxygen, sulphur and mixtures thereof, and which

rings may contain one or more double bonds or be non-aromatic, partly aromatic or wholly aromatic in character. The ring systems may be monocyclic, bicyclic or fused. Each "Het" group identified herein is optionally substituted by one or more substituents selected from halo, cyano, nitro, oxo, lower alkyl (which alkyl group may itself be optionally substituted or terminated as defined below) OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$ or $C(S)NR^{25}R^{26}$ wherein R^{19} to R^{27} each independently represent hydrogen, aryl or lower alkyl (which alkyl group itself may be optionally substituted or terminated as defined below). The term "Het" thus includes groups such as optionally substituted azetidinyl, pyrrolidinyl, imidazolyl, indolyl, furanyl, oxazolyl, isoxazolyl, oxadiazolyl, thiazolyl, thiadiazolyl, triazolyl, oxatriazolyl, thiatriazolyl, pyridazinyl, morpholinyl, pyrimidinyl, pyrazinyl, quinolinyl, isoquinolinyl, piperidinyl, pyrazolyl and piperazinyl. Substitution at Het may be at a carbon atom of the Het ring or, where appropriate, at one or more of the heteroatoms.

"Het" groups may also be in the form of an N oxide.

The term "lower alkyl" when used herein, means C_1 to C_{10} alkyl and includes methyl, ethyl, propyl, butyl, pentyl, hexyl and heptyl groups. Unless otherwise specified, alkyl groups may, when there is a sufficient number of carbon atoms, be linear or branched, be saturated or unsaturated, be cyclic, acyclic or part cyclic/acyclic, and/or be substituted or terminated by one or more substituents selected from halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$, $C(S)NR^{25}R^{26}$,

aryl or Het, wherein R^{19} to R^{27} each independently represent hydrogen, aryl or lower alkyl, and/or be interrupted by one or more oxygen or sulphur atoms, or by silano or dialkylsilcon groups.

Lower alkyl groups or alkyl groups which R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}, R^{19}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{26}, R^{27}, K, D, E and Z may represent and with which aryl and Het may be substituted, may, when there is a sufficient number of carbon atoms, be linear or branched, be saturated or unsaturated, be cyclic, acyclic or part cyclic/acyclic, and/or be interrupted by one or more of oxygen or sulphur atoms, or by silano or dialkylsilicon groups, and/or be substituted by one or more substituents selected from halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$, $C(S)NR^{25}R^{26}$, aryl or Het wherein R^{19} to R^{27} each independently represent hydrogen, aryl or lower alkyl.

Similarly, the term "lower alkylene" which A, B and J (when present) represent in a compound of formula I, when used herein, includes C_1 to C_{10} groups which are bonded to other moieties at least at two places on the group and is otherwise defined in the same way as "lower alkyl".

Halo groups with which the above-mentioned groups may be substituted or terminated include fluoro, chloro, bromo and iodo.

Where a compound of a formula herein contains an alkenyl group, cis (E) and trans (Z) isomerism may also occur. The present invention includes the individual stereoisomers of

the compounds of any of the formulas defined herein and, where appropriate, the individual tautomeric forms thereof, together with mixtures thereof. Separation of diastereoisomers or cis and trans isomers may be achieved by conventional techniques, e.g. by fractional crystallisation, chromatography or H.P.L.C. of a stereoisomeric mixture of a compound one of the formulas or a suitable salt or derivative thereof. An individual enantiomer of a compound of one of the formulas may also be prepared from a corresponding optically pure intermediate or by resolution, such as by H.P.L.C. of the corresponding racemate using a suitable chiral support or by fractional crystallisation of the diastereoisomeric salts formed by reaction of the corresponding racemate with a suitable optically active acid or base, as appropriate.

All stereoisomers are included within the scope of the process of the invention.

It will be appreciated by those skilled in the art that the compounds of formula I may function as ligands that coordinate with the Group VIB or Group VIIIB metal or compound thereof in the formation of the catalyst system of the invention. Typically, the Group VIB or Group VIIIB metal or compound thereof coordinates to the one or more phosphorous, arsenic and/or antimony atoms of the compound of formula I.

Preferably, R^1 to R^{18} each independently represent lower alkyl or aryl. More preferably, R^1 to R^{18} each independently represent C_1 to C_6 alkyl, C_1-C_6 alkyl phenyl (wherein the phenyl group is optionally substituted as

defined herein) or phenyl (wherein the phenyl group is optionally substituted as defined herein). Even more preferably, R^1 to R^{18} each independently represent C_1 to C_6 alkyl, which is optionally substituted as defined herein. Most preferably, R^1 to R^{18} each represent non-substituted C_1 to C_6 alkyl such as methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, tert-butyl, pentyl, hexyl and cyclohexyl.

Alternatively, or additionally, each of the groups R^1 to R^3, R^4 to R^6, R^7 to R^9, R^{10} to R^{12}, R^{13} to R^{15} or R^{16} to R^{18} together independently may form cyclic structures such as 1-norbornyl or 1-norbornadienyl. Further examples of composite groups include cyclic structures formed between R^1-R^{18}. Alternatively, one or more of the groups may represent a solid phase to which the ligand is attached.

In a particularly preferred embodiment of the present invention R^1, R^4, R^7, R^{10}, R^{13} and R^{16} each represent the same lower alkyl, aryl or Het moiety as defined herein, R^2, R^5, R^8, R^{11}, R^{14} and R^{17} each represent the same lower alkyl, aryl or Het moiety as defined herein, and R^3, R^6, R^9, R^{12}, R^{15} and R^{18} each represent the same lower alkyl, aryl or Het moiety as defined herein. More preferably R^1, R^4, R^7, R^{10}, R^{13} and R^{16} each represent the same C_1-C_6 alkyl, particularly non-substituted C_1-C_6 alkyl, such as methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, tert-butyl, pentyl, hexyl or cyclohexyl; R^2, R^5, R^8, R^{11}, R^{14} and R^{17} each independently represent the same C_1-C_6 alkyl as defined above; and R^3, R^6, R^9, R^{12}, R^{15} and R^{18} each independently represent the same C_1-C_6 alkyl as defined above. For example: R^1, R^4, R^7, R^{10}, R^{13} and R^{16} each represent methyl; R^2, R^5, R^8, R^{11}, R^{14} and R^{17} each represent

ethyl; and, R^3, R^6, R^9, R^{12}, R^{15} and R^{18} each represent n-butyl or n-pentyl.

In an especially preferred embodiment of the present invention each R^1 to R^{18} group represents the same lower alkyl, aryl, or Het moiety as defined herein. Preferably, each R^1 to R^{18} represents the same C_1 to C_6 alkyl group, particularly non-substituted C_1-C_6 alkyl, such as methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, tert-butyl, pentyl, hexyl and cyclohexyl. Most preferably, each R^1 to R^{18} represents methyl.

In the compound of formula I, preferably each Q^1, Q^2 and Q^3 (when present) are the same. Most preferably, each Q^1, Q^2 and Q^3 (when present) represents phosphorous.

Preferably, in the compound of formula I, A, B and J (when present) each independently represent C_1 to C_6 alkylene which is optionally substituted as defined herein, for example with lower alkyl groups. Preferably, the lower alkylene groups which A, B and J (when present) represent are non-substituted. A particular preferred lower alkylene which A, B and J may independently represent is $-CH_2-$ or $-C_2H_4-$. Most preferably, each of A, B and J (when present) represent the same lower alkylene as defined herein, particularly $-CH_2-$.

Preferably, in the compound of formula I when K, D, E or Z does not represent $-J-Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$, K, D, E or Z represents hydrogen, lower alkyl, phenyl or lower alkylphenyl. More preferably, K, D, E or Z represent hydrogen, phenyl, C_1-C_6 alkylphenyl or C_1-C_6 alkyl, such as

methyl, ethyl, propyl, butyl, pentyl and hexyl. Most preferably, K, D, E or Z represents hydrogen.

Preferably, in the compound of formula I when K, D, E and Z together with the carbon atoms of the aryl ring to which they are attached do not form a phenyl ring, K, D, E and Z each independently represent hydrogen, lower alkyl, phenyl or lower alkylphenyl. More preferably, K, D, E and Z each independently represent hydrogen, phenyl, C_1-C_6 alkylphenyl or C_1-C_6 alkyl, such as methyl, ethyl, propyl, butyl, pentyl and hexyl. Even more preferably, K, D, E and Z represent the same substituent. Most preferably, they represent hydrogen.

Preferably, in the compound of formula I when K, D, E or Z does not represent $-J-Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$ and K, D, E and Z together with the carbon atoms of the aryl ring to which they are attached do not form a phenyl ring, each of K, D, E and Z represent the same group selected from hydrogen, lower alkyl, aryl, or Het as defined herein; particularly hydrogen or C_1-C_6 alkyl (more particularly unsubstituted C_1-C_6 alkyl), especially hydrogen.

Preferably, in the compound of formula I when two of K, D, E and Z together with the carbon atoms of the aryl ring to which they are attached form a phenyl ring, then the phenyl ring is optionally substituted with one or more substituents selected from aryl, lower alkyl (which alkyl group may itself be optionally substituted or terminated as defined below), Het, halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$ or $C(S)NR^{25}R^{26}$ wherein R^{19} to R^{27} each independently represent hydrogen or lower alkyl (which alkyl group may itself be

optionally substituted or terminated as defined herein). More preferably, the phenyl ring is not substituted by any substituents i.e. it bears hydrogen atoms only.

Preferred compounds of formula I include those wherein:

A and B each independently represent unsubstituted C_1 to C_6 alkylene;

K, D, Z and E each independently represent hydrogen, C_1-C_6 alkyl, phenyl, C_1-C_6 alkylphenyl or -J-$Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$ where J represents unsubstituted C_1 to C_6 alkylene; or two of K, D, Z and E together with the carbon atoms of the aryl ring to which they are attached form a phenyl ring which is optionally substituted by one or more substituents selected from lower alkyl, phenyl or lower alkylphenyl.

R^1 to R^{18} each independently represent C_1 to C_6 alkyl, phenyl or C_1 to C_6 alkylphenyl.

Further preferred compounds of formula I include those wherein:

A and B both represent $-CH_2-$ or C_2H_4, particularly CH_2;

K, D, Z and E each independently represent hydrogen, C_1-C_6 alkyl phenyl or C_1-C_6 alkyl or -J-$Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$ where J is the same as A; or two of K, D, E and Z together with the carbon atoms of the aryl ring to which they are attached form an unsubstituted phenyl ring;

R^1 to R^{18} each independently represent C_1 to C_6 alkyl;

Still further preferred compounds of formula I include those wherein:

R^1 to R^{18} are the same and each represents C_1 to C_6 alkyl, particularly methyl.

Still further preferred compounds of formula I include those wherein:

K, D, Z and E are each independently selected from the group consisting of hydrogen or C_1 to C_6 alkyl, particularly where each of K, D, Z and E represent the same group, especially where each of K, D, Z and E represent hydrogen; or

K represents $-CH_2-Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$ and D, Z and E are each independently selected from the group consisting of hydrogen or C_1 to C_6 alkyl, particularly where both D and E represent the same group, especially where D, Z and E represent hydrogen.

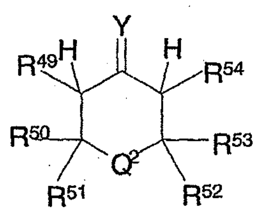
Especially preferred specific compounds of formula I include those wherein:

each R^1 to R^{12} is the same and represents methyl;
A and B are the same and represent $-CH_2-$;
K, D, Z and E are the same and represent hydrogen.

In a still further embodiment, at least one $(CR^xR^yR^z)$ group attached to Q^1 and/or Q^2, i.e. $CR^1R^2R^3$, $CR^4R^5R^6$, $CR^7R^8R^9$, or

$CR^{10}R^{11}R^{12}$, may instead be represented by the group (Ad) wherein:

Ad each independently represent an optionally substituted adamantyl or congressyl radical bonded to the phosphorous atom via any one of its tertiary carbon atoms, the said optional substitution being by one or more substituents selected from hydrogen, lower alkyl, halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}$ R^{26}, $C(S)R^{25}R^{26}$, SR^{27} or $C(O)SR^{27}$; or both $(CR^xR^yR^z)$ groups attached to either or both Q^1 and/or Q^2, or Q^3 (if present), form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group (also termed a 2-phospha-adamantyl group (2-PA-group)) or derivative thereof as more particularly defined hereinafter, or form a ring system of formula



wherein
R^{49}, and R^{54}, each independently represent hydrogen, lower alkyl or aryl;

R^{50} to R^{53}, when present, each independently represent hydrogen, lower alkyl, aryl or Het; and

Y represents oxygen, sulfur or $N-R^{55}$; and R^{55}, when present, represents hydrogen, lower alkyl or aryl.

In this embodiment, formula I may be represented as:

$$(Ad)_S(CR^7R^8R^9)_TQ^2\text{-}A\text{-}(K,D)Ar(E,Z)\text{-}B\text{-}Q^1(Ad)_u(CR^1R^2R^3)_v$$

wherein Ar, A, B, K, D, E and Z, Q^1, Q^2, and Q^3, and R^1 to R^{27} are as defined hereinbefore except that K, D, E and Z may represent $-J-Q^3(Ad)_w(CR^{13}(R^{14})(R^{15})_x$ instead of $-J-Q^3(CR^{13}(R^{14})(R^{15}))CR^{16}(R^{17})(R^{18})$ and Ad is as defined above,

S & U = 0, 1 or 2 provided that $S + U \geq 1$;
T & V = 0, 1 or 2 provided that $T + V \leq 3$;
W & X = 0, 1 or 2.

In addition to the preferred embodiments for R^1 to R^{18}, Q^1 to Q^3, A, B, J (when present), K, D, E or Z, R^{19} to R^{27}, noted hereinbefore, all of which equally apply to the present embodiment where at least one (Ad) group is present, the following also applies.

Further preferred compounds of formula I include those wherein:

A and B both represent $-CH_2-$ or $-C_2H_4-$, particularly $-CH_2-$;

K, D, Z and E each independently represent hydrogen, C_1-C_6 alkyl phenyl or C_1-C_6 alkyl or $-J-Q^3(Ad)_w(CR^{13}(R^{14})(R^{15}))_x$ where J is the same as A; or two of K, D, E and Z together with the carbon atoms of the aryl ring to which they are attached form an unsubstituted phenyl ring;

R^1 to R^3, R^7 to R^9, and R^{13} to R^{15} (when present) each independently represent C_1 to C_6 alkyl, and the total number of (Ad) groups attached to Q^1 and Q^2 is ≥ 3, i.e. $S + U \geq 3$, and W and X = 0, 1 or 2.

Still further preferred compounds of formula I include those wherein:

R^1 to R^3, R^7 to R^9 and R^{13} to R^{15} (when present) are the same and each represents C_1 to C_6 alkyl, particularly methyl, and the total number of (Ad) groups attached to Q^1 and Q^2 is ≥ 3, i.e. S + U ≥ 3.

Still further preferred compounds of formula I include those wherein:

K, D, Z and E are each independently selected from the group consisting of hydrogen or C_1 to C_6 alkyl, particularly where each of K, D, Z and E represent the same group, especially where each of K, D, Z and E represent hydrogen; or

K represents $-CH_2-Q^3(Ad)_w(CR^{13}(R^{14})(R^{15})_x$ and D, Z and E are each independently selected from the group consisting of hydrogen or C_1 to C_6 alkyl, particularly where both D and E represent the same group, especially where D, Z and E represent hydrogen, wherein W and X = 0, 1 or 2.

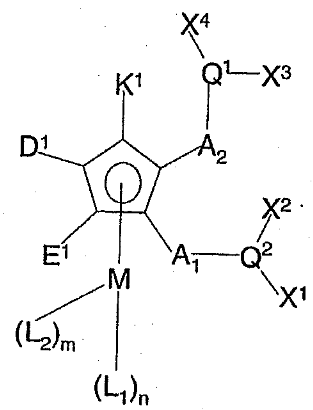
Especially preferred specific compounds of formula I include those wherein:

each R^1 to R^3, and R^7 to R^9 is the same and represents methyl or the total number of (Ad) groups attached to Q^1 and Q^2 is 2, i.e. S + U = 2;
A and B are the same and represent $-CH_2-$;
K, D, Z and E are the same and represent hydrogen.

Especially preferred specific compounds of formula I include those wherein Ad is joined to Q_1 or Q_2 at the same position in each case. Preferably $S \geq 1$ and $U \geq 1$, more preferably, $S = 2$ and $U \geq 1$ or vice versa, most preferably S & U = 2, wherein S is the number of (Ad) groups attached to Q^2 and U is the number of (Ad) groups attached to Q^1.

Specific but non-limiting examples of bidentate ligands within this embodiment include the following: 1,2 bis(diadamantylphosphinomethyl)benzene, 1,2 bis(di-3,5-dimethyladamantylphosphinomethyl)benzene, 1,2 bis(di-5-tert-butyladamantylphosphinomethyl)benzene, 1,2 bis(1-adamantyl, tert-butyl-phosphinomethyl)benzene, 1-(diadamantylphosphinomethyl)-2-(di-tert-butylphosphinomethyl)benzene, 1-(di-tert-butylphosphinomethyl)-2-(dicongressylphosphinomethyl)benzene, 1-(di-tert-butylphosphinomethyl)-2-(phospha-adamantyl-P-methyl)benzene, 1-(diadamantylphosphinomethyl)-2-(phospha-adamantyl-P-methyl)benzene, 1-(tert-butyladamantylphosphinomethyl)-2-(di-adamantylphosphinomethyl)benzene and 1-[(P-(2,2,6,6,-tetra-methylphosphinan-4-one)phosphinomethyl)]-2-(phospha-adamantyl-P-methyl)benzene, wherein "phospha-adamantyl" is selected from 2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxadamantyl, 2-phospha-1,3,5-trimethyl-6,9,10 trioxadamantyl, 2-phospha-1,3,5,7-tetra(trifluoromethyl)-6,9,10-trioxadamantyl or 2-phospha-1,3,5-tri(trifluoromethyl)-6,9,10-trioxadamantyl. Nevertheless, the skilled person in the art would appreciate that other bidentate ligands can be envisaged without departing from the scope of the invention.

In a yet further embodiment, the bidentate phosphine ligand is of general formula (III).



(III)

wherein:

A_1 and A_2, and A_3, A_4 and A_5 (when present), each independently represent lower alkylene;

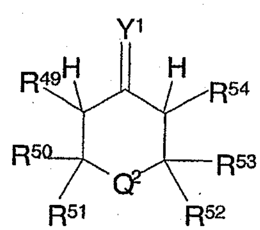
K^1 is selected from the group consisting of hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$, $-SR^{29}$, $-C(O)SR^{30}$, $-CF_3$ or $-A_3-Q^3(X^5)X^6$;

D^1 is selected from the group consisting of hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$, $-SR^{29}$, $-C(O)SR^{30}$, $-CF_3$ or $-A_4-Q^4(X^7)X^8$;

E^1 is selected from the group consisting of hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$, $-SR^{29}$, $-C(O)SR^{30}$, $-CF_3$ or $-A_5-Q^5(X^9)X^{10}$;

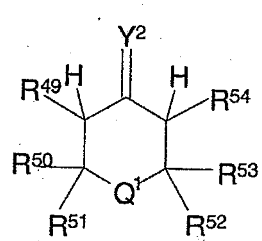
or both D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an optionally substituted phenyl ring:

X^1 represents $CR^1(R^2)(R^3)$, congressyl or adamantyl, X^2 represents $CR^4(R^5)(R^6)$, congressyl or adamantyl, or X^1 and X^2 together with Q^2 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa



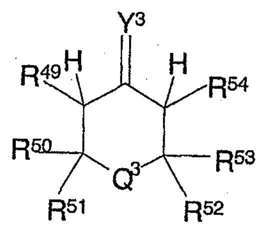
(IIIa)

X^3 represents $CR^7(R^8)(R^9)$, congressyl or adamantyl, X^4 represents $CR^{10}(R^{11})(R^{12})$, congressyl or adamantyl, or X^3 and X^4 together with Q^1 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb



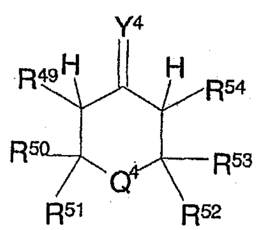
(IIIb)

X^5 represents $CR^{13}(R^{14})(R^{15})$, congressyl or adamantyl, X^6 represents $CR^{16}(R^{17})(R^{18})$, congressyl or adamantyl, or X^5 and X^6 together with Q^3 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^5 and X^6 together with Q^3 to which they are attached form a ring system of formula IIIc



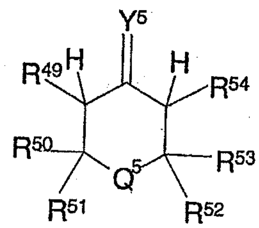
(IIIc)

X^7 represents $CR^{31}(R^{32})(R^{33})$, congressyl or adamantyl, X^8 represents $CR^{34}(R^{35})(R^{36})$, congressyl or adamantyl, or X^7 and X^8 together with Q^4 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^7 and X^8 together with Q^4 to which they are attached form a ring system of formula IIId



(IIId)

X^9 represents $CR^{37}(R^{38})(R^{39})$, congressyl or adamantyl, X^{10} represents $CR^{40}(R^{41})(R^{42})$, congressyl or adamantyl, or X^9 and X^{10} together with Q^5 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1.{3,7}]decyl group or derivative thereof, or X^9 and X^{10} together with Q^5 to which they are attached form a ring system of formula IIIe



(IIIe)

and in this yet further embodiment,

Q^1 and Q^2, and Q^3, Q^4 and Q^5 (when present), each independently represent phosphorus, arsenic or antimony;

M represents a Group VIB or VIIIB metal or metal cation thereof;

L_1 represents an optionally substituted cyclopentadienyl, indenyl or aryl group;

L_2 represents one or more ligands each of which are independently selected from hydrogen, lower alkyl, alkylaryl, halo, CO, $P(R^{43})(R^{44})R^{45}$ or $N(R^{46})(R^{47})R^{48}$;

R^1 to R^{18} and R^{31} to R^{42}, when present, each independently represent hydrogen, lower alkyl, aryl, halo or Het;

R^{19} to R^{30} and R^{43} to R^{48}, when present, each independently represent hydrogen, lower alkyl, aryl or Het;

R^{49}, R^{54} and R^{55}, when present, each independently represent hydrogen, lower alkyl or aryl;

R^{50} to R^{53}, when present, each independently represent hydrogen, lower alkyl, aryl or Het;

Y^1, Y^2, Y^3, Y^4 and Y^5, when present, each independently represent oxygen, sulfur or N-R^{55};

n = 0 or 1;

and m = 0 to 5;

provided that when n = 1 then m equals 0, and when n equals 0 then m does not equal 0.

Preferably in a compound of formula III when both K^1 represents $-A_3-Q^3(X^5)X^6$ and E^1 represents $-A_5-Q^5(X^9)X^{10}$, then D^1 represents $-A_4-Q^4(X^7)X^8$.

Preferably, in this embodiment, R^1 to R^{18} and R^{31} to R^{42}, when present, each independently represent hydrogen, optionally substituted C_1 to C_6 alkyl, C_1-C_6 alkyl phenyl (wherein the phenyl group is optionally substituted as defined herein), trifluoromethyl or phenyl (wherein the phenyl group is optionally substituted as defined herein). Even more preferably, R^1 to R^{18} and R^{31} to R^{42}, when present, each independently represent hydrogen, C_1 to C_6 alkyl, which is optionally substituted as defined herein, trifluoromethyl or optionally substituted phenyl. Even more preferably, R^1 to R^{18} and R^{31} to R^{42}, when present each independently represent hydrogen, non-substituted C_1 to C_6 alkyl or phenyl which is optionally substituted with one or more substituents selected from non-substituted C_1 to C_6 alkyl or OR^{19} where R^{19} represents hydrogen or unsubstituted C_1 to C_6 alkyl. More preferably, R^1 to R^{18} and R^{31} to R^{42}, when present, each independently represent hydrogen or non-substituted C_1 to C_6 alkyl such as methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, tert-

butyl, pentyl, hexyl and cyclohexyl, especially methyl. Most preferably, R^1 to R^{18} and R^{31} to R^{42} when present, each independently represent non-substituted C_1 to C_6 alkyl such as methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, tert-butyl, pentyl, hexyl and cyclohexyl, especially methyl.

Alternatively, or additionally, one or more of the groups R^1 to R^3, R^4 to R^6, R^7 to R^9, R^{10} to R^{12}, R^{13} to R^{15}, R^{16} to R^{18}, R^{31} to R^{33}, R^{34} to R^{36}, R^{37} to R^{39} or R^{40} to R^{42} (when present) together with the carbon atom to which they are attached independently may form cyclic alkyl structures such as 1-norbornyl or 1-norbornadienyl.

Alternatively, or additionally, one or more of the groups R^1 and R^2, R^4 and R^5, R^7 and R^8, R^{10} and R^{11}, R^{13} and R^{14}, R^{16} and R^{17}, R^{31} and R^{32}, R^{34} and R^{35}, R^{37} and R^{38} or R^{40} and R^{41} (when present) together with the carbon atom to which they are attached independently may form a cyclic alkyl structures, preferably a C_5 to C_7 cyclic alkyl structure such as cyclohexyl and cyclopentyl, and R^3, R^6, R^9, R^{12}, R^{15}, R^{18}, R^{33}, R^{36}, R^{39} and R^{42} (when present) each independently represent hydrogen, lower alkyl, trifluoromethyl or aryl as defined above, particularly non-substituted C_1 to C_6 alkyl and hydrogen, especially non-substituted C_1 to C_6 alkyl.

In an especially preferred embodiment, each of R^1 to R^{18} and R^{31} to R^{42}, when present, do not represent hydrogen. Suitably, such an arrangement means Q^1, Q^2, Q^3, Q^4 and Q^5 are bonded to a carbon atom of X^1 to X^{10}, respectively, which bears no hydrogen atoms.

Preferably, R^1, R^4, R^7, R^{10}, R^{13}, R^{16}, R^{31}, R^{34}, R^{37} and R^{40} (when present), each represent the same substituent as defined herein; R^2, R^5, R^8, R^{11}, R^{14}, R^{17}, R^{32}, R^{35}, R^{38} and R^{41} (when present), each represent the same substituent as defined herein; and R^3, R^6, R^9, R^{12}, R^{15}, R^{18}, R^{33}, R^{36}, R^{39} and R^{42} (when present), each represent the same substituent as defined herein. More preferably R^1, R^4, R^7, R^{10}, R^{13}, R^{16}, R^{31}, R^{34}, R^{37} and R^{40} (when present) each represent the same C_1-C_6 alkyl, particularly non-substituted C_1-C_6 alkyl, such as methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, tert-butyl, pentyl, hexyl or cyclohexyl, or trifluoromethyl; R^2, R^5, R^8, R^{11}, R^{14}, R^{17}, R^{32}, R^{35}, R^{38} and R^{41} (when present), each independently represent the same C_1-C_6 alkyl as defined above, or trifluoromethyl; and R^3, R^6, R^9, R^{12}, R^{15}, R^{18}, R^{33}, R^{36}, R^{39} and R^{42} (when present), each independently represent the same C_1-C_6 alkyl as defined above, or trifluoromethyl. For example: R^1, R^4, R^7, R^{10}, R^{13} and R^{16} (when present) each represent methyl; R^2, R^5, R^8, R^{11}, R^{14} and R^{17} each represent ethyl (when present); and, R^3, R^6, R^9, R^{12}, R^{15} and R^{18} (when present) each represent n-butyl or n-pentyl.

In an especially preferred embodiment each R^1 to R^{18} and R^{31} to R^{42} group (when present) represents the same substituent as defined herein. Preferably, each R^1 to R^{18} and R^{31} to R^{42} group represents the same C_1 to C_6 alkyl group, particularly non-substituted C_1-C_6 alkyl, such as methyl, ethyl, n-propyl, iso-propyl, n-butyl, iso-butyl, tert-butyl, pentyl, hexyl and cyclohexyl, or trifluoromethyl. Most preferably, each R^1 to R^{18} and R^{31} to R^{42} group represents non-substituted C_1-C_6 alkyl, particularly methyl.

The term adamantyl when used herein means an adamantyl group which may be bonded to Q^1, Q^2, Q^3, Q^4 and Q^5, respectively, in position 1 or 2. Tricyclo[3.3.1.1.{3,7}]decyl is the systematic name for an adamantyl group, suitably Q^1, Q^2, Q^3, Q^4 and Q^5, respectively, may be bonded to the 1 position or 2 position of one or two tricyclo[3.3.1.1.{3,7}]decyl groups. Preferably, Q^1 and Q^2, and Q^3, Q^4 and Q^5, when present, is bonded to a tertiary carbon of one or more adamantyl groups. Suitably, when the adamantyl group represents unsubstituted adamantyl, Q^1 and Q^2, and Q^3, Q^4 and Q^5 when present are preferably bonded to the 1 position of one or more tricyclo[3.3.1.1{3,7}]decyl groups i.e. the carbon atom of the adamantyl group bears no hydrogen atom.

The adamantyl group may optionally comprise, besides hydrogen atoms, one or more substituents selected from lower alkyl, $-OR^{19}$, $-OC(O)R^{20}$, halo, nitro, $-C(O)R^{21}$, $-C(O)OR^{22}$, cyano, aryl, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$, $-CF_3$, $-P(R^{56})R^{57}$, $-PO(R^{58})(R^{59})$, $-PO_3H_2$, $-PO(OR^{60})(OR^{61})$, or $-SO_3R^{62}$, wherein R^{19}, R^{20}, R^{21}, R^{22}, R^{23}, R^{24}, R^{25}, R^{26}, R^{27}, R^{28}, lower alkyl, cyano and aryl are as defined herein and R^{56} to R^{62} each independently represent hydrogen, lower alkyl, aryl or Het.

Suitably, when the adamantyl group is substituted with one or more substituents as defined above, highly preferred substituents include unsubstituted C_1 to C_8 alkyl, $-OR^{19}$, $-OC(O)R^{20}$, phenyl, $-C(O)OR^{22}$, fluoro, $-SO_3H$, $-N(R^{23})R^{24}$, $-P(R^{56})R^{57}$, $-C(O)N(R^{25})R^{26}$ and $-PO(R^{58})(R^{59})$, $-CF_3$, wherein R^{19} represents hydrogen, unsubstituted C_1-C_8 alkyl or phenyl, R^{20}, R^{22}, R^{23}, R^{24}, R^{25}, R^{26} each independently represent

hydrogen or unsubstituted C_1-C_8 alkyl, R^{56} to R^{53}, R^{56} each independently represent unsubstituted C_1-C_8 alkyl or phenyl.

Suitably, the adamantyl group may comprise, besides hydrogen atoms, up to 10 substituents as defined above, preferably up to 5 substituents as defined above, more preferably up to 3 substituents as defined above. Suitably, when the adamantyl group comprises, besides hydrogen atoms, one or more substituents as defined herein, preferably each substituent is identical. Preferred substituents are unsubstituted C_1-C_8 alkyl and trifluoromethyl, particularly unsubstituted C_1-C_8 alkyl such as methyl. A highly preferred adamantyl group comprises hydrogen atoms only i.e. the adamantyl group is not substituted.

Preferably, when more than one adamantyl group is present in a compound of formula III, each adamantyl group is identical.

By the term 2-phospha-tricyclo[3.3.1.1.{3,7}]decyl group we mean a 2-phospha-adamantyl group formed by the combination of X^1 and X^2 together with Q^2 to which they are attached, a 2-phospha-adamantyl group formed by the combination of X^3 and X^4 together with Q^1 to which they are attached, a 2-phospha-adamantyl group formed by the combination of X^5 and X^6 together with Q^3 to which they are attached, a 2-phospha-adamantyl group formed by the combination of X^7 and X^8 together with Q^4 to which they are attached and a 2-phospha-adamantyl group formed by the combination of X^9 and X^{10} together with Q^5 to which they are attached, wherein Q^1, Q^2, Q^3, Q^4 and Q^5 is in the 2-

position of the adamantyl group of which it forms an integral part and each of Q^1, Q^2, Q^3, Q^4 and Q^5 represents phosphorus.

The 2-phospha-tricyclo[3.3.1.1.{3,7}]decyl group (referred to as 2-phospha-adamantyl group herein) may optionally comprise, beside hydrogen atoms, one or more substituents. Suitable substituents include those substituents as defined herein in respect of the adamantyl group. Highly preferred substituents include lower alkyl, particularly unsubstituted C_1-C_8 alkyl, especially methyl, trifluoromethyl, $-OR^{19}$ wherein R^{19} is as defined herein particularly unsubstituted C_1-C_8 alkyl or aryl, and 4-dodecylphenyl. When the 2-phospha-adamantyl group includes more than one substituent, preferably each substituent is identical.

Preferably, the 2-phospha-adamantyl group is substituted on one or more of the 1, 3, 5 or 7 positions with a substituent as defined herein. More preferably, the 2-phospha-adamantyl group is substituted on each of the 1, 3 and 5 positions. Suitably, such an arrangement means the phosphorous atom of the 2-phospha-adamantyl group is bonded to carbon atoms in the adamantyl skeleton having no hydrogen atoms. Most preferably, the 2-phospha-adamantyl group is substituted on each of the 1, 3, 5 and 7 positions. When the 2-phospha-adamantyl group includes more than 1 substituent preferably each substituent is identical. Especially preferred substituents are unsubstituted C_1-C_8 alkyl and trifluoromethyl, particularly unsubstituted C_1-C_8 alkyl such as methyl.

Preferably, the 2-phospha-adamantyl group includes additional heteroatoms, other than the 2-phosphorous atom, in the 2-phospha-adamantyl skeleton. Suitable additional heteroatoms include oxygen and sulphur atoms, especially oxygen atoms. More preferably, the 2-phospha-adamantyl group includes one or more additional heteroatoms in the 6, 9 and 10 positions. Even more preferably, the 2-phospha-adamantyl group includes an additional heteroatom in each of the 6, 9 and 10 positions. Most preferably, when the 2-phospha-adamantyl group includes two or more additional heteroatoms in the 2-phospha-adamantyl skeleton, each of the additional heteroatoms are identical. An especially preferred 2-phospha-adamantyl group, which may optionally be substituted with one or more substituents as defined herein, includes an oxygen atom in each of the 6, 9 and 10 positions of the 2-phospha-adamantyl skeleton.

Highly preferred 2-phospha-adamantyl groups as defined herein include 2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxadamantyl group, 2-phospha-1,3,5-trimethyl-6,9,10-trioxadamantyl group, 2-phospha-1,3,5,7-tetra(trifluoromethyl)-6,9,10-trioxadamantyl group, and 2-phospha-1,3,5-tri(trifluoromethyl)-6,9,10-trioxadamantyl group. Most preferably, the 2-phospha-adamantyl is selected from 2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxadamantyl group or 2-phospa-1,3,5,-trimethyl-6,9,10-trioxadamantyl group.

Preferably, when more than one 2-phospha-adamantyl group is present in a compound of formula III, each 2-phospha-adamantyl group is identical.

The above definition of the term "2-phospha-tricyclo[3.3.1.1.{3,7}]decyl group" applies equally to the group when it is present in formula I but wherein X^n in formula III, i.e. X^1, X^2, X^3...X^{10}, is denoted $CR^xR^yR^z$, i.e. $CR^1R^2R^3$,...$CR^{16}R^{17}R^{18}$, in formula I.

The term congressyl when used herein means a congressyl group (also known as diamantyl group) which may be bonded to Q^1, Q^2, Q^3, Q^4 and Q^5 respectively. Preferably, Q^1 and Q^2, and Q^3, Q^4 and Q^5, when present, are bonded to one of the tertiary carbon atoms of the congressyl groups. Suitably, when the congressyl group is unsubstituted, Q^1 and Q^2, and Q^3, Q^4 and Q^5 when present, are preferably bonded to the 1-position of one or more congressyl groups.

The congressyl group may optionally comprise, beside hydrogen atoms, one or more substituents. Suitable substituents include those substituents as defined herein in respect of the adamantyl group. Highly preferred substituents include unsubstituted C_1-C_6 alkyl groups, particularly methyl, and trifluoromethyl. Most preferably, the congressyl group is unsubstituted and comprises hydrogen atoms only.

Preferably, when more than one congressyl group is present in a compound of formula III, each congressyl group is identical.

Preferably, where one or more ring systems of formula IIIa, IIIb, IIIc, IIId or IIIe are present in a compound of formula III, R^{50} to R^{53} each independently represent lower alkyl, aryl or Het, which groups are optionally substituted and/or terminated as defined herein. Such an

arrangement means Q^2, Q^1, Q^3, Q^4 and Q^5 of the ring system of formula IIIa to IIIe, respectively, is not bonded to a carbon atom bearing a hydrogen atom. Even more preferably, R^{50} to R^{53} each independently represent optionally substituted C_1-C_6 alkyl, preferably non-substituted C_1-C_6 alkyl, phenyl optionally substituted with non-substituted C_1-C_6 alkyl or OR^{19} where R^{19} represents non-substituted C_1-C_6 alkyl, or trifluoromethyl. Even more preferably R^{50} to R^{53} each represent the same group as defined herein, particularly non-substituted C_1-C_6 alkyl, especially methyl.

Preferably, where one or more ring system of formula IIIa to IIIe are present in a compound of formula III, R^{49} and R^{54} each independently represent optionally substituted C_1-C_6 alkyl, preferably non-substituted C_1-C_6 alkyl, phenyl optionally substituted with non-substituted C_1-C_6 alkyl or OR^{19} where R^{19} represents non-substituted C_1-C_6 alkyl, trifluoromethyl or hydrogen. More preferably, R^{49} and R^{54} represent the same group as defined herein, especially hydrogen.

Preferably, where one or more ring systems of formula IIIa to IIIe are present in a compound of formula III, Y^1 to Y^5 are identical. Most preferably, each of Y^1 to Y^5 represents oxygen. Preferably, where more than one ring system of formula IIIa to IIIe is present in a compound of formula III, each such ring system is identical.

Preferred embodiments of the present invention include those wherein:

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents $CR^{10}(R^{11})(R^{12})$;

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents adamantyl, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents adamantyl;

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents congressyl, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents congressyl;

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, and X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb or a 2-phospha-adamantyl group;

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents adamantyl, X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb or a 2-phospha-adamantyl group;

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents congressyl, X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb or a 2-phospha-adamantyl group;

X^1 to X^4 each independently represent adamantyl;

X^1 to X^4 each independently represent congressyl;

X^1 and X^2 each independently represent adamantyl and X^3 and X^4 each independently represent congressyl;

X^1 and X^3 independently represent adamantyl and X^2 and X^4 independently represent congressyl;

X^1 and X^2 independently represent adamantyl, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents $CR^{10}(R^{11})(R^{12})$;

X^1 and X^2 independently represent congressyl, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents $CR^{10}(R^{11})(R^{12})$;

X^1 and X^2 independently represent adamantyl, and X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb or a 2-phospha-adamantyl group;

X^1 and X^2 independently represent congressyl, and X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb or a 2-phospha-adamantyl group;

X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa, and X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb;

X^1 and X^2 together with Q^2 to which they are attached form a 2-phospha-adamantyl group, and X^3 and X^4 together with Q^1 to which they are attached form a 2-phospha-adamantyl group;

Highly preferred embodiments of the present invention include those wherein:

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents $CR^{10}(R^{11})(R^{12})$;

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents adamantyl, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents adamantyl;

X^1 represents $CR^1(R^2)(R^3)$, X^2 represents congressyl, X^3 represents $CR^7(R^8)(R^9)$ and X^4 represents congressyl;

X^1 to X^4 each independently represent adamantyl;

X^1 to X^4 each independently represent congressyl;

X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa, and X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb;

X^1 and X^2 together with Q^2 to which they are attached form a 2-phospha-adamantyl group, and X^3 and X^4 together with Q^1 to which they are attached form a 2-phospha-adamantyl group;

Preferably in a compound of formula III, X^1 is identical to X^3 and X^2 is identical to X^4. More preferably, X^1 is identical to X^3 and X^5, X^7 and X^9 when present, and X^2 is identical to X^4 and X^6, X^8 and X^{10} when present. Even more preferably, X^1 to X^4 are identical. Most preferably, X^1 to X^4 are identical to each of X^6 to X^{10} when present.

Preferably, in the compound of formula III, X^1 and X^2 represent identical substituents, X^3 and X^4 represent identical substituents, X^5 and X^6 (when present) represent identical substituents, X^7 and X^8 (when present) represent identical substituents, and X^9 and X^{10} (when present) represent identical substituents.

Preferably, in a compound of formula III, K^1 represents $-A_3-Q^3(X^5)X^6$, hydrogen, lower alkyl, $-CF_3$, phenyl or lower

alkyl phenyl. More preferably, K^1 represents $-A_3-Q^3(X^5)X^6$, hydrogen, unsubstituted C_1-C_6 alkyl, unsubstituted phenyl, trifluoromethyl or C_1-C_6 alkyl phenyl.

In a particular preferred embodiment K^1 in a compound of formula III represents hydrogen.

In an alternative embodiment where K^1 does not represent hydrogen, K^1 represents $-A_3-Q^3(X^5)X^6$. Preferably, X^5 is identical to X^3 or X^1, and X^6 is identical to X^2 or X^4. More preferably, X^5 is identical to both X^3 and X^1, and X^6 is identical to both X^2 and X^4. Even more preferably, $-A_3-Q^3(X^5)X^6$ is identical to either $-A_1-Q^2(X^1)X^2$ or $-A_2-Q^1(X^3)X^4$. Most preferably, $-A_3-Q^3(X^5)X^6$ is identical to both $-A_1-Q^2(X^1)X^2$ and $-A_2-Q^1(X^3)X^4$.

Most preferably, K^1 represents hydrogen in a compound of formula III.

Preferably, in the compound of formula III, D^1 represents $-A_4-Q^4(X^7)X^8$, hydrogen, lower alkyl, CF_3, phenyl or lower alkylphenyl, and E^1 represents $-A_5-Q^5(X^9)X^{10}$, hydrogen, lower alkyl, CF_3, phenyl or lower alkylphenyl, or D^1 and E^1 together with the carbons of the cyclopentadienyl ring to which they are attached form an optionally substituted phenyl ring. More preferably, D^1 represents $-A_4-Q^4(X^7)X^8$, hydrogen, phenyl, C_1-C_6 alkylphenyl, unsubstituted C_1-C_6 alkyl, such as methyl, ethyl, propyl, butyl, pentyl and hexyl, or CF_3; E^1 represents $-A_5-Q^5(X^9)X^{10}$, hydrogen, phenyl, C_1-C_6 alkylphenyl, unsubstituted C_1-C_6 alkyl such as methyl, ethyl, propyl, butyl, pentyl and hexyl, or $-CF_3$; or both D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form

a phenyl ring which is optionally substituted with one or more groups selected from phenyl, C_1-C_6 alkylphenyl, unsubstituted C_1-C_6 alkyl or $-CF_3$.

Suitably, when D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an optionally substituted phenyl ring, the metal M or cation thereof is attached to an indenyl ring system.

In a particular preferred embodiment, D^1 in a compound of formula III, represents hydrogen.

In an alternative embodiment where D^1 does not represent hydrogen, D^1 represents $-A_4-Q^4(X^7)X^8$. Preferably X^8 is identical to X^4 or X^2, and X^7 is identical to X^1 or X^3. More preferably, X^8 is identical to both X^4 and X^2, and X^7 is identical to X^1 and X^3. Even more preferably, $-A_4-Q^4(X^7)X^8$ is identical to either $-A_1-Q^2(X^1)X^2$ or $-A_2-Q^1(X^3)X^4$. Most preferably, $-A_4-Q^4(X^7)X^8$ is identical to both $-A_2-Q^1(X^3)X^4$, and $-A_3-Q^3(X^5)X^6$ if present.

In a particular preferred embodiment, E^1 in a compound of formula III represents hydrogen.

In an alternative embodiment where E^1 does not represent hydrogen, E^1 represents $-A_5-Q^5(X^9)X^{10}$. Preferably X^{10} is identical to X^4 or X^2, and X^9 is identical to X^1 or X^3. More preferably, X^{10} is identical to both X^4 and X^2, and X^9 is identical to X^1 and X^3. Even more preferably, $-A_5-Q^5(X^9)X^{10}$ is identical to either $-A_1-Q^2(X^1)X^2$ or $-A_2-Q^1(X^3)X^4$. Most preferably, $-A_5-Q^5(X^9)X^{10}$ is identical to both $-A_1-Q^2(X^1)X^2$ and $-A_2-Q^1(X^3)X^4$, and $-A_3-Q^3(X^5)X^6$ and $-A_4-Q^4(X^7)X^8$ if present.

Preferably, in the compound of formula III, when D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached do not form an optionally substituted phenyl ring, each of K^1, D^1 and E^1 represent an identical substituent.

In an alternative preferred embodiment, D^1 and E^1 together with the carbons of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring.

Highly preferred embodiments of compounds of formula III include those wherein:

K^1, D^1 and E^1 are identical substituents as defined herein, particularly where K^1, D^1 and E^1 represent hydrogen;

K^1 represents hydrogen, and D^1 and E^1 together with the carbons of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

K^1 represents $-A_3-Q^3(X^5)X^6$ as defined herein and both D^1 and E^1 represent H;

K^1 represents $-A_3-Q^3(X^5)X^6$ as defined herein and D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

K^1 represents $-A_3-Q^3(X^5)X^6$, D^1 represents $-A_4-Q^4(X^7)X^8$ and E^1 represents $-A_5-Q^5(X^9)X^{10}$.

Especially preferred compounds of formula III include those where both D^1 and E^1 represent hydrogen or D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring, particularly those compounds where both D^1 and E^1 represent hydrogen.

Preferably, in the compound of formula III, A_1 and A_2, and A_3, A_4 and A_5 (when present), each independently represent C_1 to C_6 alkylene which is optionally substituted as defined herein, for example with lower alkyl groups. Suitably, A_1 and A_2, and A_3, A_4 and A_5 (when present) may include a chiral carbon atom. Preferably, the lower alkylene groups which A_1 to A_5 may represent are non-substituted. A particular preferred lower alkylene, which A_1 to A_5 may independently represent, is $-CH_2-$ or $-C_2H_4-$. Most preferably, each of A_1 and A_2, and A_3, A_4 and A_5 (when present), represent the same lower alkylene as defined herein, particularly $-CH_2-$.

In the compound of formula III, preferably each Q^1 and Q^2, and Q^3, Q^4 and Q^5 (when present) are the same. Most preferably, each Q^1 and Q^2, and Q^3, Q^4 and Q^5 (when present), represents phosphorus.

It will be appreciated by those skilled in the art that the compounds of formula III may function as ligands that coordinate with the Group VIB or Group VIIIB metal or compound thereof in the formation of the catalyst system of the invention. Typically, the Group VIB or Group VIIIB metal or compound thereof coordinates to the one or more phosphorus, arsenic and/or antimony atoms of the compound of formula III. It will be appreciated that the compounds

of formula III may be referred to broadly as "metallocenes".

Suitably, when n = 1 and L_1 represents an optionally substituted cyclopentadienyl or indenyl group, the compounds of formula III may contain either two cyclopentadienyl rings, two indenyl rings or one indenyl and one cyclopentadienyl ring (each of which ring systems may optionally be substituted as described herein). Such compounds may be referred to as "sandwich compounds" as the metal M or metal cation thereof is sandwiched by the two ring systems. The respective cyclopentadienyl and/or indenyl ring systems may be substantially coplanar with respect to each other or they may be tilted with respect to each other (commonly referred to as bent metallocenes).

Alternatively, when n = 1 and L_1 represents aryl, the compounds of the invention may contain either one cyclopentadienyl or one indenyl ring (each of which ring systems may optionally be substituted as described herein) and one aryl ring which is optionally substituted as defined herein. Suitably, when n = 1 and L_1 represents aryl then the metal M of the compounds of formula III as defined herein is typically in the form of the metal cation.

In a particularly preferred embodiment of the present invention, in a compound of formula III, n = 1, L_1 is as defined herein and m = 0.

Preferably, when n = 1 in the compound of formula III, L_1 represents cyclopentadienyl, indenyl or aryl ring each of which rings are optionally substituted by one or more

substituents selected from hydrogen, lower alkyl, halo, cyano, nitro, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$ $-SR^{29}$, $-C(O)SR^{30}$, $-CF_3$ or ferrocenyl (by which we mean the cyclopentadienyl, indenyl or aryl ring which L_1 may represent is bonded directly to the cyclopentadienyl ring of the ferrocenyl group), wherein R^{19} to R^{30} is as defined herein. More preferably, if the cyclopentadienyl, indenyl or aryl ring which L_1 may represent is substituted it is preferably substituted with one or more substituents selected from unsubstituted C_1-C_6 alkyl, halo, cyano, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$ where R^{19}, R^{20}, R^{21}, R^{22}, R^{23} and R^{24} each independently represent hydrogen or C_1-C_6 alkyl. Even more preferably, if the cyclopentadienyl, indenyl or aryl ring which L_1 may represent is substituted, it is preferably substituted with one or more substituents selected from unsubstituted C_1-C_6 alkyl.

Preferably, when $n = 1$, L_1 represents cyclopentadienyl, indenyl, phenyl or napthyl optionally substituted as defined herein. Preferably, the cyclopentadienyl, indenyl, phenyl or napthyl groups are unsubstituted. More preferably, L_1 represents cyclopentadienyl, indenyl or phenyl, each of which rings are unsubstituted. Most preferably, L_1 represents unsubstituted cyclopentadienyl.

Alternatively, when $n = 0$, the compounds of the invention contain only one cyclopentadienyl or indenyl ring (each of which ring systems may optionally be substituted as described herein). Such compounds may be referred to as "half sandwich compounds". Preferably, when $n = 0$ then m represents 1 to 5 so that the metal M of the compounds of formula III has an 18 electron count. In other words, when

metal M of the compounds of formula III is iron, the total number of electrons contributed by the ligands L_2 is typically five.

In a particularly preferred alternative embodiment of the present invention, in a compound of formula III, n = 0, L_2 is as defined herein and m = 3 or 4, particularly 3.

Preferably, when n is equal to zero and m is not equal to zero in a compound of formula III, L_2 represents one or more ligands each of which are independently selected from lower alkyl, halo, -CO, $-P(R^{43})(R^{44})R^{45}$ or $-N(R^{46})(R^{47})R^{48}$. More preferably, L_2 represents one or more ligands each of which are independently selected from unsubstituted C_1 to C_4 alkyl, halo, particularly chloro, -CO, $-P(R^{43})(R^{44})R^{45}$ or $-N(R^{46})(R^{47})R^{48}$, wherein R^{43} to R^{48} are independently selected from hydrogen, unsubstituted C_1 to C_6 alkyl or aryl, such as phenyl.

Suitably, the metal M or metal cation thereof in the compounds of formula III is typically bonded to the cyclopentadienyl ring(s), the cyclopentadienyl moiety of the indenyl ring(s) if present, the aryl ring if present, and/or the ligands L_2 if present. Typically, the cyclopentadienyl ring or the cyclopentadienyl moiety of the indenyl ring exhibits a pentahapto bonding mode with the metal; however other bonding modes between the cyclopentadienyl ring or cyclopentadienyl moiety of the indenyl ring and the metal, such as trihapto coordination, are also embraced by the scope of the present invention.

Most preferably, in a compound of formula III, $n = 1$, $m = 0$ and L_1 is defined herein, particularly unsubstituted cyclopentadienyl.

Preferably M represents a Group VIB or VIIIB metal. In other words the total electron count for the metal M is 18.

Preferably, in the compound of formula III, M represents Cr, Mo, Fe, Co or Ru, or a metal cation thereof. Even more preferably, M represents Cr, Fe, Co or Ru or a metal cation thereof. Most preferably, M is selected from a Group VIIIB metal or metal cation thereof. An especially preferred Group VIIIB metal is Fe. Although the metal M as defined herein may be in a cationic form, preferably it carries essentially no residual charge due to coordination with L_1 and/or L_2 as defined herein.

Especially preferred compounds of formula III include those wherein:

(1) X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$, X^4 represents $CR^{10}(R^{11})(R^{12})$, wherein each of R^1 to R^{12} independently represents unsubstituted C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^1 to R^{12} is identical, especially where each of R^1 to R^{12} represents unsubstituted C_1-C_6 alkyl, particularly methyl;
A_1 and A_2 are the same and represent $-CH_2-$;
K^1, D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
Q^1 and Q^2 both represent phosphorus;
M represents Fe;

$n = 1$ and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and $m = 0$.

(2) X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$, X^4 represents $CR^{10}(R^{11})(R^{12})$; K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 represents $CR^{13}(R^{14})(R^{15})$ and X^6 represents $CR^{16}(R^{17})(R^{18})$;
each of R^1 to R^{18} independently represent unsubstituted C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^1 to R^{18} is identical, especially where each of R^1 to R^{18} represents unsubstituted C_1-C_6 alkyl, particularly methyl;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2 and Q^3 each represent phosphorus;
D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
M represents Fe;
$n = 1$ and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and $m = 0$.

(3) X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$, X^4 represents $CR^{10}(R^{11})(R^{12})$; K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 represents $CR^{13}(R^{14})(R^{15})$ and X^6 represents $CR^{16}(R^{17})(R^{18})$;
each of R^1 to R^{18} independently represent unsubstituted C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^1 to R^{18} is identical, especially where each of R^1 to R^{18} represents unsubstituted C_1-C_6 alkyl, particularly methyl;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2 and Q^3 each represent phosphorus;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(4) X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$, X^4 represents $CR^{10}(R^{11})(R^{12})$, wherein each of R^1 to R^{12} independently represent unsubstituted C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^1 to R^{12} is identical, especially where each of R^1 to R^{12} represents unsubstituted C_1-C_6 alkyl, particularly methyl;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1 and Q^2 both represent phosphorus;

K^1 represents hydrogen or C_1-C_6 alkyl, particularly hydrogen;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(5) X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$, X^4 represents $CR^{10}(R^{11})(R^{12})$;

E^1 represents $-CH_2-Q^5(X^9)X^{10}$ wherein X^9 represents $CR^{37}(R^{38})(R^{39})$ and X^{10} represents $CR^{40}(R^{41})(R^{42})$;

each of R^1 to R^{12} and R^{37} to R^{42} independently represent unsubstituted C_1-C_6 alkyl or

trifluoromethyl, particularly where each of R^1 to R^{12} and R^{37} to R^{42} is identical, especially where each of R^1 to R^{12} and R^{37} to R^{42} represents unsubstituted C_1-C_6 alkyl, particularly methyl;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2 and Q^5 each represent phosphorus;

D^1 and K^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(6) X^1 represents $CR^1(R^2)(R^3)$, X^2 represents $CR^4(R^5)(R^6)$, X^3 represents $CR^7(R^8)(R^9)$, X^4 represents $CR^{10}(R^{11})(R^{12})$;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 represents $CR^{13}(R^{14})(R^{15})$ and X^6 represents $CR^{16}(R^{17})(R^{18})$;

D^1 represents $-CH_2-Q^4(X^7)X^8$ wherein X^7 represents $CR^{31}(R^{32})(R^{33})$ and X^8 represents $CR^{34}(R^{35})(R^{36})$;

E^1 represents $-CH_2-Q^5(X^9)X^{10}$ wherein X^9 represents $CR^{37}(R^{38})(R^{39})$ and X^{10} represents $CR^{40}(R^{41})(R^{42})$;

each of R^1 to R^{18} and R^{31} to R^{42} independently represent unsubstituted C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^1 to R^{18} and R^{31} to R^{42} is identical, especially where each of R^1 to R^{18} and R^{31} to R^{42} represents unsubstituted C_1-C_6 alkyl, particularly methyl;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2, Q^3, Q^4 and Q^5 each represent phosphorus

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(7) X^1, X^2, X^3 and X^4 independently represent adamantyl, especially where X^1 to X^4 represent the same adamantyl group;
A_1 and A_2 are the same and represent $-CH_2-$;
K^1, D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
Q^1 and Q^2 both represent phosphorus;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(8) X^1, X^2, X^3 and X^4 independently represent adamantyl, especially where X^1 to X^4 represent the same adamantyl group;
K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 independently represent adamantyl, especially where X^1 to X^6 represent the same adamantyl group;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2 and Q^3 each represent phosphorus;
D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(9) X^1, X^2, X^3 and X^4 independently represent adamantyl, especially where X^1 to X^4 represent the same adamantyl group;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 independently represent adamantyl, especially where X^1 to X^6 represent the same adamantyl group;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2 and Q^3 each represent phosphorus;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(10) X^1, X^2, X^3 and X^4 independently represent adamantyl, especially where X^1 to X^4 represent the same adamantyl group;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1 and Q^2 both represent phosphorus;

K^1 represents hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(11) X^1, X^2, X^3 and X^4 independently represent adamantyl;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 independently represent adamantyl;

D^1 represents $-CH_2-Q^4(X^7)X^8$ wherein X^7 and X^8 independently represents adamantyl;

E^1 represents $-CH_2-Q^5(X^9)X^{10}$ wherein X^9 and X^{10} independently represents adamantyl, especially where X^1 to X^{10} represent the same adamantyl group;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2, Q^3, Q^4 and Q^5 each represent phosphorus;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(12) X^1 and X^2 together with Q^2 to which they are attached represents 2-phospha-adamantyl;
X^3 and X^4 together with Q^1 to which they are attached represents 2-phospha-adamantyl;
A_1 and A_2 are the same and represent $-CH_2-$;
K^1, D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
Q^1 and Q^2 both represent phosphorus;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(13) X^1 and X^2 together with Q^2 to which they are attached represents 2-phospha-adamantyl;
X^3 and X^4 together with Q^1 to which they are attached represents 2-phospha-adamantyl;
K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 together with Q^3 to which they are attached represents 2-phospha-adamantyl;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2 and Q^3 each represent phosphorus;

D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(14) X^1 and X^2 together with Q^2 to which they are attached represents 2-phospha-adamantyl;
X^3 and X^4 together with Q^1 to which they are attached represents 2-phospha-adamantyl;
K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 together with Q^3 to which they are attached represents 2-phospha-adamantyl;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2 and Q^3 each represent phosphorus;
D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(15) X^1 and X^2 together with Q^2 to which they are attached represents 2-phospha-adamantyl;
X^3 and X^4 together with Q^1 to which they are attached represents 2-phospha-adamantyl;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1 and Q^2 both represent phosphorus;
K^1 represents hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(16) X^1 and X^2 together with Q^2 to which they are attached represents 2-phospha-adamantyl;

X^3 and X^4 together with Q^1 to which they are attached represents 2-phospha-adamantyl;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 together with Q^3 to which they are attached represents 2-phospha-adamantyl;

D^1 represents $-CH_2-Q^4(X^7)X^8$ wherein X^7 and X^8 together with Q^4 to which they are attached represents 2-phospha-adamantyl;

E^1 represents $-CH_2-Q^5(X^9)X^{10}$ wherein X^9 and X^{10} together with Q^5 to which they are attached represents 2-phospha-adamantyl;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2, Q^3, Q^4 and Q^5 each represent phosphorus

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(17) X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa, X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb, wherein Y^1 and Y^2 both represent oxygen, R^{50} to R^{53} are independently

selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;
A_1 and A_2 are the same and represent $-CH_2-$;
K^1, D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
Q^1 and Q^2 both represent phosphorus;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl (referred to as puc) and m = 0.

(18) X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa, X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb, wherein Y^1 and Y^2 both represent oxygen, R^{50} to R^{53} are independently selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;
K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 together with Q^3 to which they are attached form a ring system of formula IIIc, wherein Y^3 represents oxygen, R^{50} to R^{53} are independently selected from hydrogen, unsubstituted C_1-C_6 alkyl or CF_3 and R^{49} and R^{54} represent hydrogen;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2 and Q^3 each represent phosphorus;
D^1 and E^1 are the same and represent hydrogen or C_1-C_6 alkyl, particularly hydrogen;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(19) X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa, X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb, wherein Y^1 and Y^2 both represent oxygen, R^{50} to R^{53} are independently selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 together with Q^3 to which they are attached form a ring system of formula IIIc, wherein Y^3 represents oxygen, R^{50} to R^{53} are independently selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2 and Q^3 each represent phosphorus;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(20) X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa, X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb, wherein Y^1 and Y^2 both represent oxygen, R^{50} to R^{53} are independently selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1 and Q^2 both represent phosphorus;

K^1 represents hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(21) X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa, X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb, wherein Y^1 and Y^2 both represent oxygen, R^{50} to R^{53} are independently selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 together with Q^3 to which they are attached form a ring system of formula IIIc, wherein Y^3 represents oxygen, R^{50} to R^{53} are independently selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;

D^1 represents $-CH_2-Q^4(X^7)X^8$ wherein X^7 and X^8 together with Q^4 to which they are attached form a ring system of formula IIIc, wherein Y^3 represents oxygen, R^{50} to R^{53} are independently selected from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;

E^1 represents $-CH_2-Q^5(X^9)X^{10}$ wherein X^9 and X^{10} together with Q^5 to which they are attached form a ring system of formula IIIe, wherein Y^5 represents oxygen, and R^{50} to R^{53} are independently selected

from unsubstituted C_1-C_6 alkyl or CF_3, and R^{49} and R^{54} represent hydrogen;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2, Q^3, Q^4 and Q^5 each represent phosphorus;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl; particularly unsubstituted cyclopentadienyl, and m = 0.

(22) X^1, X^2, X^3 and X^4 independently represent congressyl, especially where X^1 to X^4 represent the same congressyl group;

A_1 and A_2 are the same and represent $-CH_2-$;

K^1, D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

Q^1 and Q^2 both represent phosphorus;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(23) X^1, X^2, X^3 and X^4 independently represent congressyl, especially where X^1 to X^4 represent the same congressyl group;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 independently represent congressyl, especially where X^1 to X^6 represent the same congressyl group;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2 and Q^3 each represent phosphorus;

D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(24) X^1, X^2, X^3 and X^4 independently represent congressyl, especially where X^1 to X^4 represent the same congressyl group;
K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 independently represent congressyl, especially where X^1 to X^6 represent the same congressyl group;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2 and Q^3 each represent phosphorus;
D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;
M represents Fe;
n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(25) X^1, X^2, X^3 and X^4 independently represent congressyl, especially where X^1 to X^4 represent the same congressyl group;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1 and Q^2 both represent phosphorus;
K^1 represents hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;
M represents Fe;

$n = 1$ and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and $m = 0$.

(26) X^1, X^2, X^3 and X^4 independently represent congressyl;
K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 and X^6 independently represent congressyl;
D^1 represents $-CH_2-Q^4(X^7)X^8$ wherein X^7 and X^8 independently represents congressyl;
E^1 represents $-CH_2-Q^5(X^9)X^{10}$ wherein X^9 and X^{10} independently represents congressyl, especially where X^1 to X^{10} represent the same congressyl group;
A_1 and A_2 are the same and represent $-CH_2-$;
Q^1, Q^2, Q^3, Q^4 and Q^5 each represent phosphorus;
M represents Fe;
$n = 1$ and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and $m = 0$.

(27) X^1 and X^3 independently represent adamantyl, especially where X^1 and X^3 represent the same adamantyl group;
X^2 represents $CR^4(R^5)(R^6)$ and X^4 represents $CR^{10}(R^{11})(R^{12})$ wherein each of R^4, R^5, R^6, R^{10}, R^{11} and R^{12} independently represent C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^4 to R^6 and R^{10} to R^{12} is identical, especially where each of R^4 to R^6 and R^{10} to R^{12} represents unsubstituted C_1-C_6 alkyl, particularly methyl;
A_1 and A_2 are the same and represent $-CH_2-$;
K^1, D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;
Q^1 and Q^2 both represent phosphorus;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(28) X^1 and X^3 independently represent adamantyl, especially where X^1 and X^3 represent the same adamantyl group;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 represents adamantyl, especially where X^1, X^3 and X^5 represent the same adamantyl group;

X^2 represents $CR^4(R^5)(R^6)$, X^4 represents $CR^{10}(R^{11})(R^{12})$, X^6 represents $CR^{16}(R^{17})(R^{18})$, wherein each of R^4 to R^6, R^{10} to R^{12} and R^{16} to R^{18} independently represent unsubstituted C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^4 to R^6, R^{10} to R^{12}, and R^{16} to R^{18} is identical, especially where each of R^4 to R^6, R^{10} to R^{12} and R^{16} to R^{18} represents unsubstituted C_1-C_6 alkyl, particularly methyl;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2 and Q^3 each represent phosphorus;

D^1 and E^1 are the same and represent hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(29) X^1 and X^3 independently represent adamantyl, especially where X^1 and X^3 represent the same adamantyl group;

K^1 represents $-CH_2-Q^3(X^5)X^6$ wherein X^5 represents adamantyl, especially where X^1, X^3 and X^5 represent the same adamantyl group;

X^2 represents $CR^4(R^5)(R^6)$, X^4 represents $CR^{10}(R^{11})(R^{12})$, X^6 represents $CR^{16}(R^{17})(R^{18})$, wherein each of R^4 to R^6, R^{10} to R^{12} and R^{16} to R^{18} independently represent unsubstituted C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^4 to R^6, R^{10} to R^{12}, and R^{16} to R^{18} is identical, especially where each of R^4 to R^6, R^{10} to R^{12} and R^{16} to R^{18} represents unsubstituted C_1-C_6 alkyl, particularly methyl;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1, Q^2 and Q^3 each represent phosphorus;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

(30) X^1 and X^3 independently represent adamantyl, especially where X^1 and X^3 represent the same adamantyl group;

X^2 represents $CR^4(R^5)(R^6)$ and X^4 represents $CR^{10}(R^{11})(R^{12})$ wherein each of R^4, R^5, R^6, R^{10}, R^{11} and R^{12} independently represent C_1-C_6 alkyl or trifluoromethyl, particularly where each of R^4 to R^6 and R^{10} to R^{12} is identical, especially where each of R^4 to R^6 and R^{10} to R^{12} represents unsubstituted C_1-C_6 alkyl, particularly methyl;

A_1 and A_2 are the same and represent $-CH_2-$;

Q^1 and Q^2 both represent phosphorus;

K^1 represents hydrogen or unsubstituted C_1-C_6 alkyl, particularly hydrogen;

D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an unsubstituted phenyl ring;

M represents Fe;

n = 1 and L_1 represents cyclopentadienyl, particularly unsubstituted cyclopentadienyl, and m = 0.

Specific but non-limiting examples of bidentate ligands within this embodiment include the following: 1,2-bis-(dimethylaminomethyl)ferrocene, 1,2-bis-(ditertbutylphosphinomethyl)ferrocene, 1-hydroxymethyl-2-dimethylaminomethylferrocene, 1,2-bis-(ditertbutylphosphinomethyl)ferrocene, 1-hydroxymethyl-2,3-bis-(dimethylaminomethyl)ferrocene, 1,2,3-tris-(ditertbutylphosphinomethyl)ferrocene, 1,2-bis-(dicyclohexylphosphinomethyl)ferrocene, 1,2-bis-(di-iso-butylphosphinomethyl)ferrocene, 1,2-bis-(dicyclopentylphosphinomethyl)ferrocene, 1,2-bis-(diethylphosphinomethyl)ferrocene, 1,2-bis(di-isopropylphosphinomethyl)ferrocene, 1,2-bis-(dimethylphosphinomethyl)ferrocene, 1,2-bis-(di-(1,3,5,7-tetramethyl-6,9,10-trioxa-2-phospha-adamantylmethyl))ferrocene, 1,2-bis-(dimethylaminomethyl)ferrocene-bismethyl iodide, 1,2-bis(dihydroxymethylphosphinomethyl)ferrocene, 1,2-bis(diphosphinomethyl)ferrocene, 1,2-bis-α,α-(P-(2,2,6,6,-tetramethylphosphinan-4-one))dimethylferrocene, and 1,2-bis-(di-1,3,5,7-tetramethyl-6,9,10-trioxa-2-phospha-adamantylmethyl))benzene. Nevertheless, the skilled person in the art would appreciate that other bidentate

ligands can be envisaged without departing from the scope of the invention.

According to a further aspect, the present invention provides a process for the carbonylation of an ethylenically unsaturated compound comprising contacting an ethylenically unsaturated compound with carbon monoxide and a hydroxyl group containing compound in the presence of a catalyst system as defined in the present invention. Preferably, the process is a liquid phase continuous process comprising the step noted above.

Suitably, the hydroxyl group containing compound includes water or an organic molecule having a hydroxyl functional group. Preferably, the organic molecule having a hydroxyl functional group may be branched or linear, and comprises an alkanol, particularly a C_1-C_{30} alkanol, including aryl alkanols, which may be optionally substituted with one or more substituents selected from lower alkyl, aryl, Het, halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, $C(S)R^{25}R^{26}$, SR^{27} or $C(O)SR^{28}$ as defined herein. Highly preferred alkanols are C_1-C_8 alkanols such as methanol, ethanol, propanol, iso-propanol, iso-butanol, t-butyl alcohol, n-butanol, phenol and chlorocapryl alcohol. Although the monoalkanols are most preferred, poly-alkanols, preferably, selected from di-octa ols such as diols, triols, tetra-ols and sugars may also be utilised. Typically, such polyalkanols are selected from 1, 2-ethanediol, 1,3-propanediol, glycerol, 1,2,4 butanetriol, 2-(hydroxymethyl)-1,3-propanediol, 1,2,6 trihydroxyhexane, pentaerythritol, 1,1,1 tri(hydroxymethyl)ethane, nannose, sorbase, galactose and other sugars. Preferred sugars include sucrose, fructose

and glucose. Especially preferred alkanols are methanol and ethanol. The most preferred alkanol is methanol.

The amount of alcohol is not critical. Generally, amounts are used in excess of the amount of ethylenically unsaturated compound to be carbonylated. Thus the alcohol may serve as the reaction solvent as well, although, if desired, separate solvents may also be used.

It will be appreciated that the end product of the reaction is determined at least in part by the source of hydroxyl group containing compound used. If water is used as the hydroxyl group containing compound then the end product is the corresponding carboxylic acid, whereas use of an alkanol produces the corresponding ester.

It will also be appreciated that the process of the present invention may start with a catalyst system having components providing molar ratios above or below those claimed but such ratios will progress to values within said ranges claimed during the course of the reaction.

It will of course also be appreciated that the levels of such components present within the catalyst system may change during the process of the invention as further amounts of some or all of the components are added to maintain the usable levels of components within the catalyst system. Some of the components of the catalyst system may drop out of the system during the reaction process and therefore levels may need to be topped-up to maintain levels within the actual catalyst system.

As stated hereinbefore, it will be appreciated by those skilled in the art that the phosphines described herein may function as ligands that coordinate with the Group VIB or Group VIIIB metal or compound, together with the present acid, to form a complex. This complex may represent part of the effective catalyst in the present invention and hence may represent part of the catalyst system defined herein.

In the process according to the present invention, the carbon monoxide may be used in pure form or diluted with an inert gas such as nitrogen, carbon dioxide or a noble gas such as argon. Small amounts of hydrogen, typically less than 5% by volume, may also be present.

The ratio (volume/volume) of ethylenically unsaturated compound to hydroxyl group containing compound may vary between wide limits and suitably lies in the range of 1:0.1 to 1:10, preferably from between 2:1 to 1:2 and up to a large excess of hydroxyl group containing compounds when the latter is also the reaction solvent such as up to a 50:1 excess of hydroxyl group containing compounds.

The molar ratio of the ethylenically unsaturated compound to carbon monoxide is preferably in the range 1:1 to 100:1 more preferably greater than 1:1, even more preferably at least 3:1, especially from 3:1 to 50:1, and most preferably in the range from 3:1 to 15:1.

The total amount of dissolved Group VIB or VIIIB metal of the invention used in the carbonylation process of the ethylenically unsaturated compound is not critical. Good results may be obtained when, preferably, the amount of

Group VIB or VIIIB metal is in the range 10^{-7} to 10^{-1} moles per mole of ethylenically unsaturated compound, more preferably, 10^{-6} to 10^{-2} moles, most preferably 10^{-5} to 10^{-2} moles per mole of ethylenically unsaturated compound. Preferably, the amount of bidentate compound of formula I or formula III to unsaturated compound is in the range 10^{-7} to 10^{-1}, more preferably, 10^{-6} to 10^{-2}, most preferably, 10^{-5} to 10^{-2} moles per mole of ethylenically unsaturated compound.

Suitably, although non-essential to the invention, the carbonylation of an ethylenically unsaturated compound as defined herein may be performed in one or more aprotic solvents. Suitable solvents include ketones, such as for example methylbutylketone; ethers, such as for example anisole (methyl phenyl ether), 2,5,8-trioxanonane (diglyme), diethyl ether, dimethyl ether, tetrahydrofuran, diphenylether, diisopropylether and the dimethylether of di-ethylene-glycol; esters, such as for example methylacetate, dimethyladipate methyl benzoate, dimethyl phthalate and butyrolactone; amides, such as for example dimethylacetamide, N-methylpyrrolidone and dimethyl formamide; sulfoxides and sulphones, such as for example dimethylsulphoxide, di-isopropylsulphone, sulfolane (tetrahydrothiophene-2,2-dioxide), 2-methylsulfolane, diethyl sulphone, tetrahydrothiophene 1,1-dioxide and 2-methyl-4-ethylsulfolane; aromatic compounds, including halo variants of such compounds eg. benzene, toluene, ethyl benzene o-xylene, m-xylene, p-xylene, chlorobenzene, o-dichlorobenzene, m-dichlorobenzene: alkanes, including halo variants of such compounds eg, hexane, heptane, 2,2,3-trimethylpentane, methylene chloride and carbon tetrachloride; nitriles eg. benzonitrile and acetonitrile.

Very suitable are aprotic solvents having a dielectric constant that is below a value of 50, more preferably in the range of 3 to 8, at 298.15 K and $1 \times 10^5 Nm^{-2}$. In the present context, the dielectric constant for a given solvent is used in its normal meaning of representing the ratio of the capacity of a condenser with that substance as dielectric to the capacity of the same condenser with a vacuum for dielectric. Values for the dielectric constants of common organic liquids can be found in general reference books, such as the Handbook of Chemistry and Physics, 76^{th} edition, edited by David R. Lide et al, and published by CRC press in 1995, and are usually quoted for a temperature of about 20ºC or 25ºC, i.e. about 293.15k or 298.15 K, and atmospheric pressure, i.e. about $1 \times 10^5 Nm^{-2}$, or can readily be converted to that temperature and pressure using the conversion factors quoted. If no literature data for a particular compound is available, the dielectric constant may be readily measured using established physico-chemical methods.

For example, the dielectric constant of anisole is 4.3 (at 294.2 K), of diethyl ether is 4.3 (at 293.2 K), of sulfolane is 43.4 (at 303.2 K), of methylpentanoate is 5.0 (at 293.2 K), of diphenylether is 3.7 (at 283.2 K), of dimethyladipate is 6.8 (at 293.2 K), of tetrahydrofuran is 7.5 (at 295.2 K), of methylnonanoate is 3.9 (at 293.2 K). A preferred solvent is anisole.

If the hydroxyl group containing compound is an alkanol, an aprotic solvent will be generated by the reaction because the ester carbonylation product of the

ethylenically unsaturated compound, carbon monoxide and the alkanol is an aprotic solvent.

The process may be carried out in an excess of aprotic solvent, i.e. at a ratio (v/v) of aprotic solvent to hydroxyl group containing compound of at least 1:1. Preferably, this ratio ranges from 1:1 to 10:1 and more preferably from 1:1 to 5:1. Most preferably the ratio (v/v) ranges from 1.5:1 to 4:1.

Despite the aforegoing it is preferred that the reaction is carried out in the absence of any external added aprotic solvent ie. an aprotic solvent not generated by the reaction itself.

The catalyst compounds of the present invention act as "homogeneous" catalysts.

By the term "homogeneous" catalyst we mean a catalyst, i.e. a compound of the invention, which is not supported but is simply admixed or formed in-situ with the reactants of the carbonylation reaction (e.g. the ethylenically unsaturated compound, the hydroxyl containing compound and carbon monoxide), preferably in a suitable solvent as described herein.

Conveniently, the process of the invention may be carried out by dissolving the Group VIB or VIIIB metal or compound thereof as defined herein in a suitable solvent such as one of the hydroxyl group containing compounds or aprotic solvents previously described (a particularly preferred solvent would be the ester or acid product of the specific carbonylation reaction e.g. Methyl propionate for ethylene

carbonylation) and subsequently admixing with a compound of formula I or III as defined herein and an acid.

The carbon monoxide may be used in the presence of other gases which are inert in the reaction. Examples of such gases include hydrogen, nitrogen, carbon dioxide and the noble gases such as argon.

Suitable Group VIB or VIIIB metals or a compound thereof which may be combined with a compound of formula I or III include cobalt, nickel, palladium, rhodium, platinum, chromium, molybdenum and tungsten, and preferably include colbalt, nickel, palladium, rhodium and platinum. Preferably, the component b) is a Group VIIIB metal or a compound thereof. Preferably, the metal is a Group VIIIB metal, such as palladium. Preferably, the Group VIIIB metal is palladium or a compound thereof. Thus, component b) is preferably palladium or a compound thereof. Suitable compounds of such Group VIB or VIIIB metals include salts of such metals with, or compounds comprising weakly coordinated anions derived from, nitric acid; sulphuric acid; lower alkanoic (up to C_{12}) acids such as acetic acid and propionic acid; sulphonic acids such as methane sulphonic acid, chlorosulphonic acid, fluorosulphonic acid, trifluoromethane sulphonic acid, benzene sulphonic acid, naphthalene sulphonic acid, toluene sulphonic acid, e.g. p-toluene sulphonic acid, t-butyl sulphonic acid, and 2-hydroxypropane sulphonic acid; sulphonated ion exchange resins; perhalic acid such as perchloric acid; ; halogenated carboxylic acids such as trichloroacetic acid and trifluoroacetic acid; orthophosphoric acid; phosphonic acids such as benzenephosphonic acid; and acids derived from

interactions between Lewis acids and Bronsted acids. Other sources which may provide suitable anions include the optionally halogenated tetraphenyl borate derivatives, e.g. perfluorotetraphenyl borate. Additionally, zero valent palladium complexes particularly those with labile ligands, e.g. triphenylphosphine or alkenes such as dibenzylideneacetone or styrene or tri(dibenzylideneacetone)dipalladium may be used.

Thus, the acid (when present) is selected from an acid having a pKa measured in aqueous solution at 18°C of less than 6, more preferably less than 5, most preferably less than 4, especially less than 3, more especially, less than 2. Suitable acids include the acids listed supra. Preferably, the acid is either a sulphonic acid, or some other acid such as those selected from the list consisting of perchloric acid, phosphoric acid, methyl phosphonic acid, sulphuric acid, and sulphonic acids, even more preferably a sulphonic acid or other acid (selected from the list above) having a pKa measured in aqueous solution at 18°C of less than 4, yet even more preferably a sulphonic acid having a pKa measured in aqueous solution at 18°C of less than 2, still more preferably the acid is selected from the list consisting of the following sulphonic acids: methanesulphonic acid, trifluoromethanesulphonic acid, tert-butanesulphonic acid, p-toluenesulphonic acid, 2-hydroxypropane-2-sulphonic acid, and 2,4,6-trimethylbenzenesulphonic acid, most preferably the acid is methanesulphonic acid.

The anion may be derived from or introduced as one or more of an acid having a pKa measured in aqueous solution at 18°C of less than 6, more preferably, less than 5, most

preferably, less than 4, especially less than 3, a salt with a cation that does not interfere with the reaction, e.g. metal salts or largely organic salts such as alkyl ammonium, and a precursor, such as an ester, that can break down under reaction conditions to generate the anion in situ. Suitable acids and salts include the acids and salts, listed supra.

The quantity of anion present is not critical to the catalytic behaviour of the catalyst system. The molar ratio of anion to metal may be from 1:1 to 500:1, preferably from 2:1 to 100:1 and particularly from 3:1 to 30:1. Where the anion is provided by a combination of acid and salt, the relative proportion of the acid and salt is not critical.

As mentioned, the catalyst system of the present invention is typically used homogeneously.

The catalyst system of the present invention is preferably constituted in the liquid phase which may be formed by one or more of the reactants or by the use of a suitable solvent.

The molar ratio of the amount of ethylenically unsaturated compound used in the reaction to the amount of hydroxyl providing compound is not critical and may vary between wide limits, e.g. from 0.001:1 to 100:1 mol/mol.

The product of the carbonylation reaction using the ligand of the invention may be separated from the other components by any suitable means. However, it is an advantage of the present process that significantly fewer

by-products are formed thereby reducing the need for further purification after the initial separation of the product as may be evidenced by the generally significantly higher selectivity. A further advantage is that the other components which contain the catalyst system which may be recycled and/or reused in further reactions with minimal supplementation of fresh catalyst.

Preferably, the carbonylation is carried out at a temperature of between -10 to 150°C, more preferably 0°C to 140°C, even more preferably 15°C to 140°C, most preferably 20°C to 120°C. An especially preferred temperature is one chosen between 80°C to 120°C. Advantageously, the carbonylation can be carried out at moderate temperatures.

Preferably, when operating a low temperature carbonylation, the carbonylation is carried out between -30°C to 49°C, more preferably, -10°C to 45°C, still more preferably 0°C to 45°C, even more preferably 10°C to 45°C, most preferably 15°C to 45°C. Especially preferred is a range of 15 to 35°C.

Preferably, the carbonylation is carried out at a CO partial pressure of between 0.80×10^5 $N.m^{-2}$ to $90 \times 10^5 N.m^{-2}$, more preferably, 1×10^5 $N.m^{-2}$ to $65 \times 10^5 N.m^{-2}$ and most preferably 1 to 30×10^5 $N.m^{-2}$. Especially preferred is a CO partial pressure of 5 to $20 \times 10^5 N.m^{-2}$.

Preferably, a low pressure carbonylation is also envisaged. Preferably, when operating a low pressure carbonylation the carbonylation is carried out at a CO partial pressure of between 0.1 to $5 \times 10^5 N.m^{-2}$, more

preferably 0.2 to 2 x $10^5 N.m^{-2}$ and most preferably 0.5 to 1.5 x $10^5 N.m^{-2}$.

The ethylenically unsaturated compounds may be substituted or non-substituted with groups as defined above for the "aryl" group above. Particularly suitable substituents include alkyl and aryl groups as well as groups containing heteroatoms such as halides, sulphur, phosphorus, oxygen and nitrogen. Examples of substituents include chloride, bromide, iodide and hydroxy, alkoxy, carboxy, amino, amido, nitro, cyano, thiol or thioalkoxy groups. Suitable ethylenically unsaturated compounds include ethene, propene, hexene, vinyl compounds such as vinyl acetates, heptene, octene, nonene, decene, undecene, dodecene, etc up to C_{30}, i.e. having from 2 to 30 carbon atoms, which may be linear or branched, cyclic or uncyclic or part cyclic and in which the double bond may take any suitable position in the carbon chain and which includes all stereisomers thereof.

Moreover, the unsaturated compound may have one or more unsaturated bonds and therefore, for example, the range of ethylenically unsaturated compounds extends to dienes. The unsaturated bond(s) may be internal or terminal, the catalyst system of the invention being particularly advantageous in the conversion of internal olefins.

Particularly preferred are olefins having from 2 to 22 carbon atoms per molecule, such as ethene, propene, 1-butene, 2-butene, isobutene, pentenes, hexenes, octenes, e.g. oct-2-ene, oct-3-ene, oct-4-ene, decenes and dodecenes, triisobutylene, tripropylene, internal C_{14} olefins, and internal C_{15}-C_{18} olefins, 1,5-cyclooctadiene,

cyclododecene, methyl pentenoate and pentene nitriles, e.g. pent-2-ene nitrile.

The ethylenically unsaturated compound is preferably an alkene having 1 to 3 carbon-carbon double bonds per molecule. Non-limiting examples of suitable dienes include the following: 1,3-butadiene, 2-methyl-1,3-butadiene, 1,5-cyclooctadiene, 1,3-cyclohexadiene, 2,4-heptadiene, 1,3-pentadiene, 1,3-hexadiene, particularly 1,3-butadiene.

Another preferred category of unsaturated compounds consists of unsaturated esters of carboxylic acids and esters of unsaturated carboxylic acids. For example, the starting material may be a vinyl ester of a carboxylic acid such as acetic acid or propanoic acid, or it may be an alkyl ester of an unsaturated acid, such as the methyl or ethyl ester of acrylic acid or methacrylic acid.

A further preferred category of unsaturated compounds consists of cycloalkadienes, which will ordinarily refuse carbonylation. For example, the starting material may be dicyclopentadiene or norbornadiene, to give diesters, diamides or diacids, etc., which may find subsequent use as monomers in polymerisation reactions.

The use of stabilising compounds with the catalyst system may also be beneficial in improving recovery of metal which has been lost from the catalyst system. When the catalyst system is utilized in a liquid reaction medium such stabilizing compounds may assist recovery of the Group VI or VIIIB metal.

Preferably, therefore, the catalyst system includes in a liquid reaction medium a polymeric dispersant dissolved in a liquid carrier, said polymeric dispersant being capable of stabilising a colloidal suspension of particles of the Group VI or VIIIB metal or metal compound of the catalyst system within the liquid carrier.

The liquid reaction medium may be a solvent for the reaction or may comprise one or more of the reactants or reaction products themselves. The reactants and reaction products in liquid form may be miscible with or dissolved in a solvent or liquid diluent.

The polymeric dispersant is soluble in the liquid reaction medium, but should not significantly increase the viscosity of the reaction medium in a way which would be detrimental to reaction kinetics or heat transfer. The solubility of the dispersant in the liquid medium under the reaction conditions of temperature and pressure should not be so great as to deter significantly the adsorption of the dispersant molecules onto the metal particles.

The polymeric dispersant is capable of stabilising a colloidal suspension of particles of said Group VI or VIIIB metal or metal compound within the liquid reaction medium such that the metal particles formed as a result of catalyst degradation are held in suspension in the liquid reaction medium and are discharged from the reactor along with the liquid for reclamation and optionally for re-use in making further quantities of catalyst. The metal particles are normally of colloidal dimensions, e.g. in the range 5 - 100 nm average particle size although larger particles may form in some cases. Portions of the

polymeric dispersant are adsorbed onto the surface of the metal particles whilst the remainder of the dispersant molecules remain at least partially solvated by the liquid reaction medium and in this way the dispersed Group VI or VIIIB metal particles are stabilised against settling on the walls of the reactor or in reactor dead spaces and against forming agglomerates of metal particles which may grow by collision of particles and eventually coagulate. Some agglomeration of particles may occur even in the presence of a suitable dispersant but when the dispersant type and concentration is optimised then such agglomeration should be at a relatively low level and the agglomerates may form only loosely so that they may be broken up and the particles redispersed by agitation.

The polymeric dispersant may include homopolymers or copolymers including polymers such as graft copolymers and star polymers.

Preferably, the polymeric dispersant has sufficiently acidic or basic functionality to substantially stabilise the colloidal suspension of said Group VI or VIIIB metal or metal compound.

By substantially stabilise is meant that the precipitation of the Group VI or VIIIB metal from the solution phase is substantially avoided.

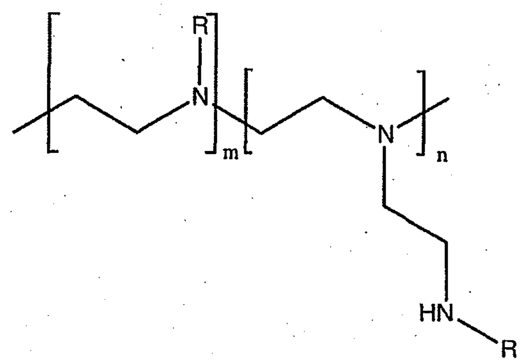
Particularly preferred dispersants for this purpose include acidic or basic polymers including carboxylic acids, sulphonic acids, amines and amides such as polyacrylates or heterocycle, particularly nitrogen

heterocycle, substituted polyvinyl polymers such as polyvinyl pyrrolidone or copolymers of the aforesaid.

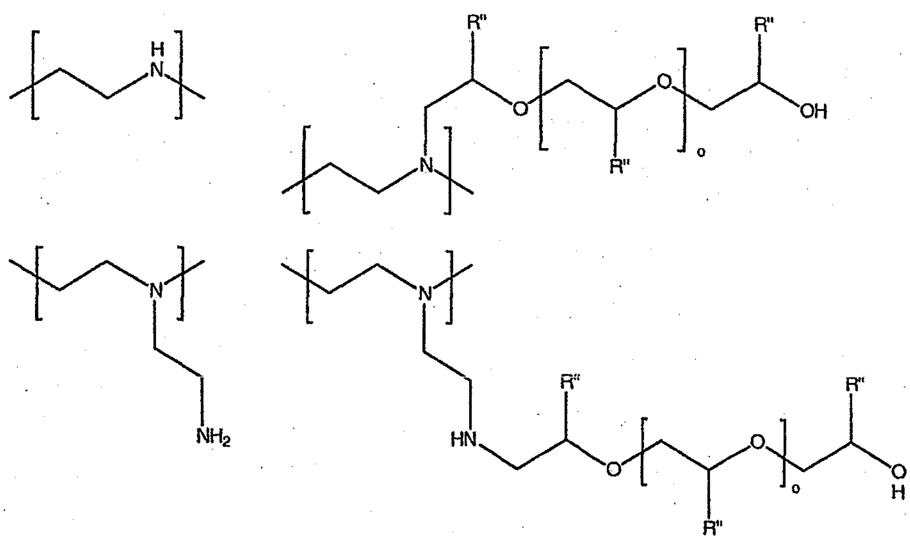
Examples of such polymeric dispersants may be selected from polyvinylpyrrolidone, polyacrylamide, polyacrylonitrile, polyethylenimine, polyglycine, polyacrylic acid, polymethacrylic acid, poly(3-hydroxybutyricacid), poly-L-leucine, poly-L-methionine, poly-L-proline, poly-L-serine, poly-L-tyrosine, poly(vinylbenzenesulphonic acid) and poly(vinylsulphonic acid).

Other suitable polymeric dispersants are nitrogen-containing polymers which are solubilizable in the reaction mixture and their methods of preparation are described in EP1330309 which are hereby incorporated by reference. Examples of suitable polymers described therein are polyalkylenimines, in particular polyethylenimines; polyvinylamines having aliphatic nitrogen-containing radicals on the polymer chain; polymers of ethylenically unsaturated carboxamides such as poly(meth)acrylamides; polymers of acyclic or cyclic N-vinyl amides such as polyvinylformamide or polyvinylcaprolactam. The polymers can have different nitrogen-containing monomers and, if desired, nitrogen-free monomers in one molecule. The nitrogen atoms may be present in the main chain or in side groups. In the case of such polymers containing amino groups, they bear, for example, substituents such as alkyl, aryl, acyl or polyoxyalkylene groups on some or all of the amino groups Preference is given to using polyethylenimines as solubilizable nitrogen-containing polymers. They

preferably comprise the polyethylenimine units of the formula (I) or (III) or the branched isomers thereof

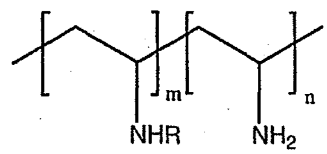


(I)



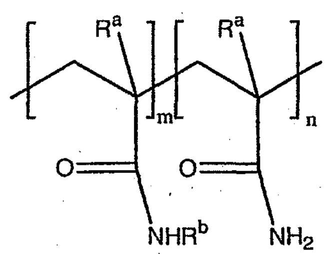
(III)

Further compounds described are derivatives of polyvinylamine which have aliphatic nitrogen-containing groups on the polymer chain and comprise, as the characteristic structural element, units of the formula (IV)



(IV)

Still further compounds suitable are derivatives of polyacrylamide which comprise, as characteristic structural elements, units of the formula (V)



(V)

A particularly preferred polymer is amidated polyethylenimine as described in EP1330309.

Other alternatives are the solubilizable carboxamides described in US publication 2003 / 0069450 and all such carboxamides are incorporated herein by reference. Generally, the carboxamides disclosed therein have at least one carboxamide group of the formula -CO-N< Such carboxamides can be, for example, saturated or unsaturated, aliphatic, aromatic or araliphatic compounds. Furthermore, the carboxamide can contain one or more heteroatoms such as oxygen, nitrogen, sulfur or

phosphorus, for example -O-, -S-, -NH-, -NR-, -CO-, -CO-O-, -N-, -CO-N<, -SiR2-, -PR- and/or -PR2 and/or be substituted by one or more functional groups containing, for example, oxygen, nitrogen, sulfur and/or halogen atoms.

Very particularly preferred carboxamides disclosed therein and having one carboxamide group of the formula -CO-N< in the molecule are N,N-dimethylacetamide, N,N-diethylacetamide, N,N-dipropylacetamide, N,N-diisopropylacetamide, N,N-dibutylacetamide, N,N-diisobutylacetamide, N,N-dipentylacetamide, N,N-dihexylacetamide, N,N-dioctylacetamide, N,N-dimethylpropionamide, N, N-diethylpropionamide, N, N-dipropylpropionamide, N,N-diisopropylpropionamide, N,N-dibutylpropionamide, N,N-diisobutylpropionamide, N,N-dipentylpropionamide, N,N-dihexylpropionamide and N,N-dioctylpropionamide.

Suitable examples of oligomeric and polymeric carboxamides given are acylated oligoalkylenimines and polyalkylenimines, in particular acylated oligoethylenimines and polyethylenimines; acylated oligovinylamines and polyvinylamines; oligomers and polymers of ethylenically unsaturated carboxamides, for example oligoacrylamides and polyacrylamides or oligomethacrylamides and polymethacrylamides; and oligomers and polymers of acyclic and cyclic N-vinyl amides, for example oligovinylformamides and polyvinylformamides or oligovinylcaprolactams and polyvinylcaprolactams.

Preferably, the polymeric dispersant incorporates acidic or basic moieties either pendant or within the polymer backbone. Preferably, the acidic moieties have a dissociation constant (pK_a) of less than 6.0, more preferably, less than 5.0, most preferably less than 4.5. Preferably, the basic moieties have a base dissociation constant (pK_b) being of less than 6.0, more preferably less than 5.0 and most preferably less than 4.5, pK_a and pK_b being measured in dilute aqueous solution at 25°C.

Suitable polymeric dispersants, in addition to being soluble in the reaction medium at reaction conditions, contain at least one acidic or basic moiety, either within the polymer backbone or as a pendant group. We have found that polymers incorporating acid and amide moieties such as polyvinylpyrollidone (PVP) and polyacrylates such as polyacrylic acid (PAA) are particularly suitable. The molecular weight of the polymer which is suitable for use in the invention depends upon the nature of the reaction medium and the solubility of the polymer therein. We have found that normally the average molecular weight is less than 100,000. Preferably, the average molecular weight is in the range 1,000 - 200,000, more preferably, 5,000 - 100,000, most preferably, 10,000 - 40,000 e.g. Mw is preferably in the range 10,000 - 80,000, more preferably 20,000 - 60,000 when PVP is used and of the order of 1,000 - 10,000 in the case of PAA.

The effective concentration of the dispersant within the reaction medium should be determined for each reaction/catalyst system which is to be used.

The dispersed Group VI or VIIIB metal may be recovered from the liquid stream removed from the reactor e.g. by filtration and then either disposed of or processed for re-use as a catalyst or other applications. In a continuous process the liquid stream may be circulated through an external heat-exchanger and in such cases it may be convenient to locate filters for the palladium particles in these circulation apparatus.

Preferably, the polymer:metal mass ratio in g/g is between 1:1 and 1000:1, more preferably, between 1:1 and 400:1, most preferably, between 1:1 and 200:1. Preferably, the polymer:metal mass ratio in g/g is up to 1000, more preferably, up to 400, most preferably, up to 200.

Preferably, said reaction medium is a liquid-phase reaction medium, more preferably a liquid-phase continuous-system reaction system.

Preferably, within said reaction medium, the amount of free acid present in the medium, that is acid which is not directly combined with the phosphine ligand, is greater than 500ppm, more preferably greater than 1000ppm, most preferably greater than 2000ppm.

For the avoidance of any doubt, each and every feature described hereinbefore is equally applicable to any or all of the various aspects of the present invention as set out supra., unless such features are incompatible with the particular aspect or are mutually exclusive.

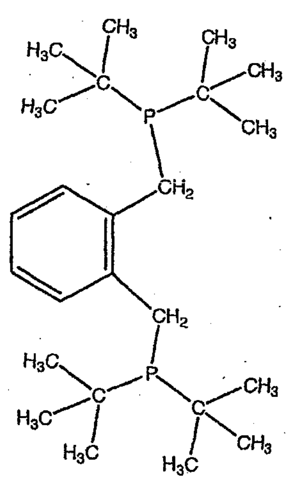
All documents mentioned herein are incorporated by reference thereto.

The following examples and figures further illustrate the present invention. These examples are to be viewed as being illustrative of specific materials falling within the broader disclosure presented above and are not to be viewed as limiting the broader disclosure in any way.

Figure 1 shows a plot of TON vs ACCF for examples 1 - 5 and 7 and comparative example 6, based upon data from the series of examples shown in Table 1. Table 2 shows data from examples 8 - 11.

Preparative Example 1

Preparation of 1,2-bis-(ditertbutylphosphinomethyl) benzene



1,2-bis-(di-tert-butylphosphinomethyl)benzene

The preparation of this ligand was carried out in the manner disclosed in WO 99/47528 in accordance with Example 18.

Preparative Example 2

Preparation of 1,2-bis-(di-(dimethyladamantyl)phosphinomethyl)ferrocene

The preparation of this ligand was carried out in the manner disclosed in WO 03/003936, in accordance with Example 1.

<u>Examples 1-5 and 7 and Comparative Example 6</u>

<u>Preparation of methyl propanoate from ethylene, carbon monoxide and methanol catalysed according to the present invention</u>

The continuous process exemplified involved the reaction of purified streams of carbon monoxide, ethylene and methanol in the liquid phase, in the presence of a catalyst system, to generate the desired product, methyl propanoate.

The reaction was carried out at 100°C and at 12 barg pressure in the reactor vessel.

The catalyst system was made up of three components, being a palladium salt, a phosphine ligand and an acid. The three catalyst components, when combined together and dissolved in the reaction mixture, constitute the reaction catalyst or catalyst system, a homogeneous catalyst, which converted dissolved reactants to the product methyl propanoate in the liquid phase.

During continuous operation, the catalyst decomposed at a slow but steady rate, and was replaced by adding fresh

catalyst, or the rate of generation of the product, methyl propanoate reduces.

The reactor vessel was fitted with an agitator, and also a means of re-circulating the unreacted gas that collected in the upper headspace area of the reactor. The unreacted gas from the reactor vessel headspace, which was made up of a mixture of ethylene and carbon monoxide, was returned continuously to the reactor via an entry pipe at the base, such that the gas passed up through the reaction mixture continuously.

Upon entering into the reactor vessel the gas was dispersed by the agitator into fine bubbles. In this way the ethylene and carbon monoxide were dissolved in the reaction mix.

Fresh ethylene and carbon monoxide gases were added to the re-circulating gas to make up for the amount of the two gases that have been used up by the reaction. Fresh methanol was also added continuously to the reactor vessel, in order to replace the methanol that has been used up in the reaction.

The reactor vessel held the bulk liquid reaction mixture, along with the three components of the homogeneous catalyst, being a palladium salt, a phosphine ligand, and a sulphonic acid.

In order to recover the product methyl propanoate, a stream of reaction mixture was passed continuously out of the reactor and into the distillation column.

The distillation column, being a single stage 'flash' type distillation column, provided a means of separating a fraction of the methyl propanoate and methanol components of the reaction mixture from the non-volatile dissolved catalyst components. This was achieved by vaporising a fraction of the reaction mixture as it passed through the flash column. The part of the reaction mixture which remained as liquid after passing through the flash column, and which still contained useful catalyst components, was returned to the reactor vessel so that the catalyst components could take part in the on-going reaction.

If the methyl propanoate product was required free of methanol, a second distillation column was required. In this case, the vapour stream from the flash column, which is a mixture of methyl propanoate and methanol was passed into the second distillation column, where the pure methyl propanoate was generated as the heavier product, and taken off from the base of the column. A low boiling mixture of methanol and methyl propanoate was generated as the light product, and was removed continuously from the top of the MeP purification column. In order to utilise the methanol as efficiently as possible in the process, the low boiling mixture of methanol and methyl propanoate was returned continuously to the reactor vessel.

After start up of the continuous reactor unit, when the desired rate of generation of methyl propanoate had been achieved, a process of gradual reduction of the feed rates of the catalyst components was undertaken.

In order to sustain the rate of generation of methyl propanoate it was necessary to continuously replace the

palladium catalyst component which was lost to decomposition with fresh palladium at a rate which balanced the rate of loss.

This led to the situation where the standing concentrations of catalyst components became constant for a given rate of generation of methyl propanoate, and just able to sustain flow sheet reaction rate, as indicated by constant concentrations of carbon monoxide and ethylene in the headspace area of the reactor vessel. This was called the balance point, because under these conditions the rate of palladium decomposition was balanced exactly by the rate of addition of fresh palladium.

From the rate of addition of fresh palladium catalyst component under balance point conditions, the palladium turnover number (TON) was calculated. This is defined as the number of mol of methyl propanoate generated per hour, for each mol of palladium consumed by the decomposition process per hour.

Upon reaching a steady state at a pre-determined set of control conditions, the instantaneous values of all of the variables were recorded, and used as representative data to show the performance of the process under the conditions in use at the time.

To gather data on the effect of ACCF on palladium turnover number, all variables were held constant except the levels of solvent in the reaction mixture. These levels were changed to a high level, a comparative low level and 5 comparative average levels to generate a reliable control level. The additions were then followed by careful

adjustment to make sure the rate of production of methyl propanoate remained constant.

In this way, comparative sets of results were drawn up which showed clearly the changes to catalyst stability that were caused by the variations in the ACCF.

The amount of palladium in the feed to the reactor is critical to calculation of turnover number results. Assurance on the rate of fresh catalyst being fed to the system was provided by analysis of each batch of catalyst prior to transfer to the catalyst feed tanks for palladium content. Further assurance was gained by determination of the actual feed rate of catalyst from timing of the fall in the level in a burette, which is part of the catalyst feed system.

Table 1 shows the effect of ACCF on palladium turnover number (TON) for results obtained for examples 1 - 5 and 7 and comparative example 6.

In examples 1 - 5 and 7 and comparative example 6, the acid used was methanesulphonic acid, the bidentate phosphine ligand was 1,2-bis-(ditertbutylphosphinomethyl)benzene, and the palladium compound was tri(dibenzylideneacetone)dipalladium.

Table 1

	Ex. 1	Ex. 7	Comp. Ex. 6	Ex. 2	Ex. 3	Ex. 4	Ex.5
Volume of Liquid Phase reactor (ml, 20C)	2600	3600	1600	2600	2600	2600	2600
Pure MeP rate (g/hr, by weight difference)	1000	1000	1000	1000	1000	1023	1024
Turn Over Number (mol MeP/Mol Pd)	5967054	11474335	4319287	6046196	6341425	6616618	6007141
Pd (ppm)	5.8	5.4	7.6	5.1			
'P' (ppm)	30	32	40	34			
Acid (ppm)	1105	1086	1190	1177			
ACCF (Kg MeP hr^{-1} dm^{-3})	0.38	0.28	0.63	0.38	0.38	0.39	0.39

The results from comparative example 6, examples 1 - 5 and example 7 are shown more clearly in figure 1 which shows a plot of TON vs ACCF. As can be seen, at low ACCF the TON surprisingly increases.

Table 1 shows the actual measured levels of Palladium at the different data points, as well as the calculated ACCF factors and resulting Pd turnover numbers.

Table 2 shows the effect of ACCF on palladium turnover number (TON), obtained for examples 8 - 11. It shows the calculated ACCF factors and resulting Pd turnover numbers.

In examples 8 - 11, the acid used was methanesulphonic acid, the bidentate phosphine ligand was 1,2-bis-(di(dimethyladamantyl)phosphinomethyl)ferrocene, and the

palladium compound was tri(dibenzylideneacetone)dipalladium.

Table 2

	Ex. 8	Ex. 9	Ex. 10	Ex. 11
Volume of Liquid Phase reactor (ml, 20C)	2600	2600	2600	3600
Pure MeP rate (g/hr, by weight difference)	1030	1035	1032	1030
Turn Over Number (mol MeP/Mol Pd)	10712078	10803755	11707192	19816656
Pd (ppm)	n/m	n/m	n/m	n/m
'P' (ppm)	n/m	n/m	n/m	n/m
Acid (ppm)	1621	n/m	n/m	1137
ACCF (Kg MeP hr^{-1} dm^{-3})	0.38	0.38	0.38	0.28

Although some preferred embodiments have been shown and described, it will be appreciated by those skilled in the art that various changes and modifications might be made without departing from the scope of the present invention, as defined in the appended claims.

Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification (including any accompanying claims, abstract and

drawings), and/or all of the steps of any method or process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.

Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

Claims

1. A continuous carbonylation process for high turnover carbonylation comprising carbonylating an ethylenically unsaturated compound with carbon monoxide in the presence of a source of hydroxyl groups and a catalyst system comprising (a) a bidentate phosphine, arsine or stibine ligand, and (b) a catalytic metal selected from a group VIB or group VIIIB metal or a compound thereof wherein the catalytically active concentration of said catalytic metal, measured as the ACCF (product $Kg.hr^{-1}.dm^{-3}$) is held at less than 0.5.

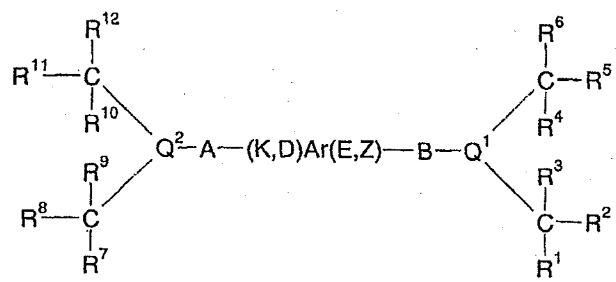
2. A carbonylation reaction medium and product stream thereof for a continuous carbonylation process comprising in the reaction medium an ethylenically unsaturated compound, carbon monoxide, a source of hydroxyl groups and a catalyst system comprising:-

(c) a bidentate phosphine, arsine or stibene ligand, and

(d) a catalytic metal selected from a group VIB or group VIIIB metal or a compound thereof wherein the catalytically active concentration of said catalytic metal in said medium, measured as the ACCF (product $kg.hr^{-1}.dm^{-3}$), is maintained at less than 0.5.

3. A process for the carbonylation of an ethylenically unsaturated compound comprising contacting an ethylenically unsaturated compound with carbon monoxide and a hydroxyl group containing compound in the presence of a catalyst system as defined in claim 1 or 2.

4. A catalyst system according to any of claims 1-3, wherein the bidentate phosphine ligand is of general formula (I)



(I)

wherein:

Ar is a bridging group comprising an optionally substituted aryl moiety to which the phosphorus atoms are linked on available adjacent carbon atoms;

A and B each independently represent lower alkylene;

K, D, E and Z are substituents of the aryl moiety (Ar) and each independently represent hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, $C(S)R^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$, or $-J-Q^3(CR^{13}(R^{14})(R^{15})CR^{16}(R^{17})(R^{18})$ where J represents lower alkylene; or two adjacent groups selected from K, Z, D and E together with the carbon atoms of the aryl ring to which they are attached form a further phenyl ring, which is optionally substituted by one or more substituents selected from hydrogen, lower alkyl, halo, cyano, nitro,

OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, $C(S)R^{25}R^{26}$, SR^{27} or $C(O)SR^{27}$;

R^{13} to R^{18} each independently represent hydrogen, lower alkyl, aryl, or Het;

R^{19} to R^{27} each independently represent hydrogen, lower alkyl, aryl or Het;

R^1 to R^{12} each independently represent hydrogen, lower alkyl, aryl, or Het;

Q^1, Q^2 and Q^3 (when present) each independently represent phosphorous, arsenic or antimony and in the latter two cases references to phosphine or phosphorous above are amended accordingly.

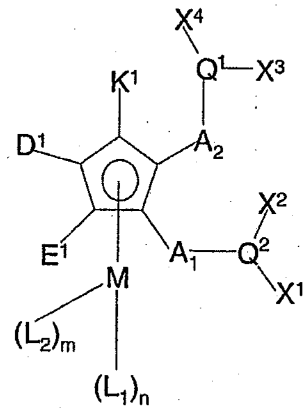
5. A continuous carbonylation process according to claim 4, wherein each Q^1, Q^2 and Q^3 (when present) represents phosphorous.

6. A continuous carbonylation process, a carbonylation reaction medium, a process for the carbonylation of an ethylenically unsaturated compound or a catalyst system, according to any of claims 1-5, wherein the low ACCF is held or maintained by suitable dilution of the carbonylation reaction medium.

7. A continuous carbonylation process, a carbonylation reaction medium, a process for the carbonylation of an ethylenically unsaturated compound or a catalyst system, according to claims 1-6, wherein the catalyst system also includes as a further compound (c), an acid.

8. A continuous carbonylation process, a carbonylation reaction medium, a process for the carbonylation of an ethylenically unsaturated compound or a catalyst system according to claims 1-7, wherein specific but non-limiting examples of bidentate ligands within this embodiment include the following: 1,2 bis(diadamantylphosphinomethyl)benzene, 1,2 bis(di-3,5-dimethyladamantylphosphinomethyl)benzene, 1,2 bis(di-5-tert-butyladamantylphosphinomethyl)benzene, 1,2 bis(1-adamantyl tert-butyl-phosphinomethyl)benzene, 1-(diadamantylphosphinomethyl)-2-(di-tert-butylphosphinomethyl)benzene, 1-(di-tert-butylphosphinomethyl)-2-(dicongressylphosphinomethyl)benzene, 1-(di-tert-butylphosphinomethyl)-2-(phospha-adamantyl-P-methyl)benzene, 1-(diadamantylphosphinomethyl)-2-(phospha-adamantyl-P-methyl)benzene, 1-(tert-butyladamantylphosphinomethyl)-2-(di-adamantylphosphinomethyl)benzene and 1-[(P-(2,2,6,6,-tetra-methylphosphinan-4-one)phosphinomethyl)]-2-(phospha-adamantyl-P-methyl)benzene, wherein "phospha-adamantyl" is selected from 2-phospha-1,3,5,7-tetramethyl-6,9,10-trioxadamantyl,2-phospha-1,3,5-trimethyl-6,9,10 trioxadamantyl, 2-phospha-1,3,5,7-tetra(trifluoromethyl)-6,9,10-trioxadamantyl or 2-phospha-1,3,5-tri(trifluoromethyl)-6,9,10-trioxadamantyl.

9. A continuous carbonylation process, a carbonylation reaction medium, a process for the carbonylation of an ethylenically unsaturated compound or a catalyst system, according to claims 1-3, 6 or 7, wherein the bidentate phosphine ligand is of general formula (III).



(III)

wherein:

A_1 and A_2, and A_3, A_4 and A_5 (when present), each independently represent lower alkylene;

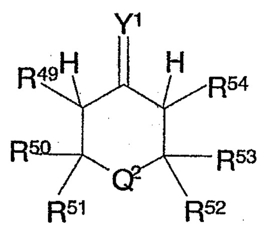
K^1 is selected from the group consisting of hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$, $-SR^{29}$, $-C(O)SR^{30}$, $-CF_3$ or $-A_3-Q^3(X^5)X^6$;

D^1 is selected from the group consisting of hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$, $-SR^{29}$, $-C(O)SR^{30}$, $-CF_3$ or $-A_4-Q^4(X^7)X^8$;

E^1 is selected from the group consisting of hydrogen, lower alkyl, aryl, Het, halo, cyano, nitro, $-OR^{19}$, $-OC(O)R^{20}$, $-C(O)R^{21}$, $-C(O)OR^{22}$, $-N(R^{23})R^{24}$, $-C(O)N(R^{25})R^{26}$, $-C(S)(R^{27})R^{28}$, $-SR^{29}$, $-C(O)SR^{30}$, $-CF_3$ or $-A_5-Q^5(X^9)X^{10}$;

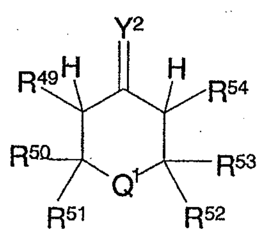
or both D^1 and E^1 together with the carbon atoms of the cyclopentadienyl ring to which they are attached form an optionally substituted phenyl ring:

X^1 represents $CR^1(R^2)(R^3)$, congressyl or adamantyl, X^2 represents $CR^4(R^5)(R^6)$, congressyl or adamantyl, or X^1 and X^2 together with Q^2 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^1 and X^2 together with Q^2 to which they are attached form a ring system of formula IIIa



(IIIa)

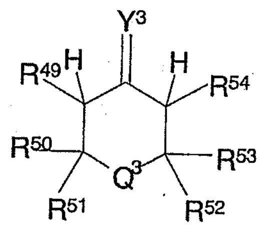
X^3 represents $CR^7(R^8)(R^9)$, congressyl or adamantyl, X^4 represents $CR^{10}(R^{11})(R^{12})$, congressyl or adamantyl, or X^3 and X^4 together with Q^1 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^3 and X^4 together with Q^1 to which they are attached form a ring system of formula IIIb



(IIIb)

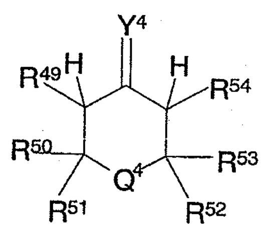
X^5 represents $CR^{13}(R^{14})(R^{15})$, congressyl or adamantyl, X^6 represents $CR^{16}(R^{17})(R^{18})$, congressyl or adamantyl, or X^5

and X^6 together with Q^3 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^5 and X^6 together with Q^3 to which they are attached form a ring system of formula IIIc



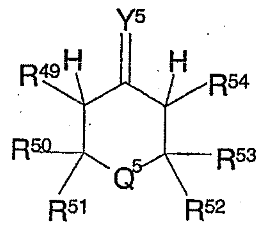
(IIIc)

X^7 represents $CR^{31}(R^{32})(R^{33})$, congressyl or adamantyl, X^8 represents $CR^{34}(R^{35})(R^{36})$, congressyl or adamantyl, or X^7 and X^8 together with Q^4 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1{3,7}]decyl group or derivative thereof, or X^7 and X^8 together with Q^4 to which they are attached form a ring system of formula IIId



(IIId)

X^9 represents $CR^{37}(R^{38})(R^{39})$, congressyl or adamantyl, X^{10} represents $CR^{40}(R^{41})(R^{42})$, congressyl or adamantyl, or X^9 and X^{10} together with Q^5 to which they are attached form an optionally substituted 2-phospha-tricyclo[3.3.1.1.{3,7}]decyl group or derivative thereof, or X^9 and X^{10} together with Q^5 to which they are attached form a ring system of formula IIIe



(IIIe)

and in this yet further embodiment,

Q^1 and Q^2, and Q^3, Q^4 and Q^5 (when present), each independently represent phosphorus, arsenic or antimony;

M represents a Group VIB or VIIIB metal or metal cation thereof;

L_1 represents an optionally substituted cyclopentadienyl, indenyl or aryl group;

L_2 represents one or more ligands each of which are independently selected from hydrogen, lower alkyl, alkylaryl, halo, CO, $P(R^{43})(R^{44})R^{45}$ or $N(R^{46})(R^{47})R^{48}$;

R^1 to R^{18} and R^{31} to R^{42}, when present, each independently represent hydrogen, lower alkyl, aryl, halo or Het;

R^{19} to R^{30} and R^{43} to R^{48}, when present, each independently represent hydrogen, lower alkyl, aryl or Het;

R^{49}, R^{54} and R^{55}, when present, each independently represent hydrogen, lower alkyl or aryl;

R^{50} to R^{53}, when present, each independently represent hydrogen, lower alkyl, aryl or Het;

Y^1, Y^2, Y^3, Y^4 and Y^5, when present, each independently represent oxygen, sulfur or $N-R^{55}$;

n = 0 or 1;

and m = 0 to 5;

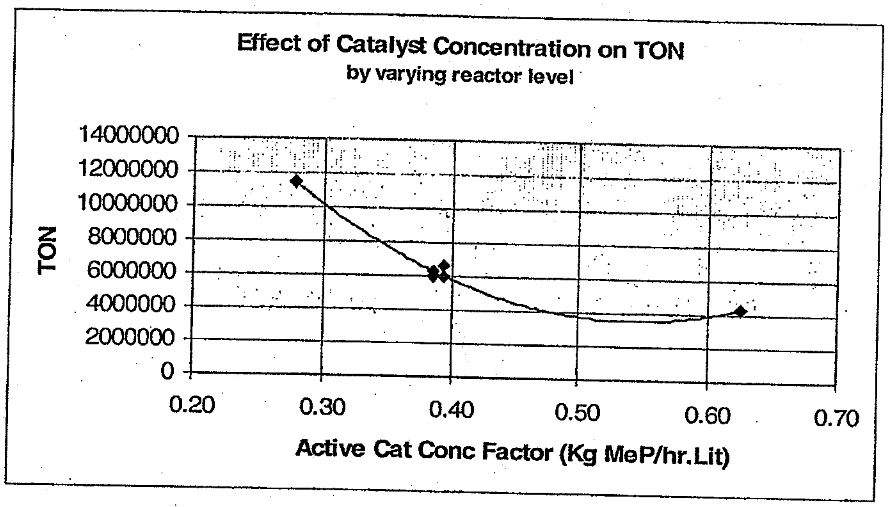
provided that when n = 1 then m equals 0, and when n equals 0 then m does not equal 0.

10. A continuous carbonylation process, a carbonylation reaction medium, a process for the carbonylation of an ethylenically unsaturated compound or a catalyst system, according to claims 1-9, wherein the hydroxyl group containing compound includes water or an organic molecule having a hydroxyl functional group.

11. A continuous carbonylation process, a carbonylation reaction medium, a process for the carbonylation of an ethylenically unsaturated compound or a catalyst system, according to claims 1-10, wherein the ethylenically unsaturated compounds may (a) be non-substituted or substituted with lower alkyl (which alkyl group may itself be substituted, unsubstituted or terminated as defined herein), aryl, Het, halo, cyano, nitro, thioalkoxy, OR^{19}, $OC(O)R^{20}$, $C(O)R^{21}$, $C(O)OR^{22}$, $NR^{23}R^{24}$, $C(O)NR^{25}R^{26}$, $C(S)R^{25}R^{26}$, $C(S)NR^{25}R^{26}$, SR^{27}, $C(O)SR^{27}$, wherein R^{19} to R^{27} each independently represent hydrogen, aryl or lower alkyl (which alkyl group may itself be substituted, unsubstituted or terminated as defined below); (b) have from 2 to 30 carbon atoms, which may be linear or branched, cyclic or uncyclic or part cyclic; and (c) may have one or more unsaturated carbon-carbon bonds.

12. A continuous carbonylation process, a carbonylation reaction medium, a process for the carbonylation of an ethylenically unsaturated compound or a catalyst system, according to any preceding claim, wherein the Group VIB or VIIIB metal or a compound thereof is selected from Groups 6, 8, 9 and 10 of the modern periodic table.

Figure 1


Effect of Catalyst Concentration on TON
by varying reactor level
TON
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
0.20
0.30
0.40
0.50
0.60
0.70
Active Cat Conc Factor (Kg MeP/hr.Lit)

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2006/002915

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01J31/24 C07C51/14

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B01J C07C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

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X	WO 2004/014834 A (LUCITE INT UK LTD [GB]; EASTHAM GRAHAM RONALD [GB]; JIMENEZ CRISTINA [) 19 February 2004 (2004-02-19) the whole document	1-8, 10-12
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 October 2006	30/10/2006

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bork, Ana-Maria

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2006/002915

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2006/002915

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Form PCT/ISA/210 (patent family annex) (April 2005)